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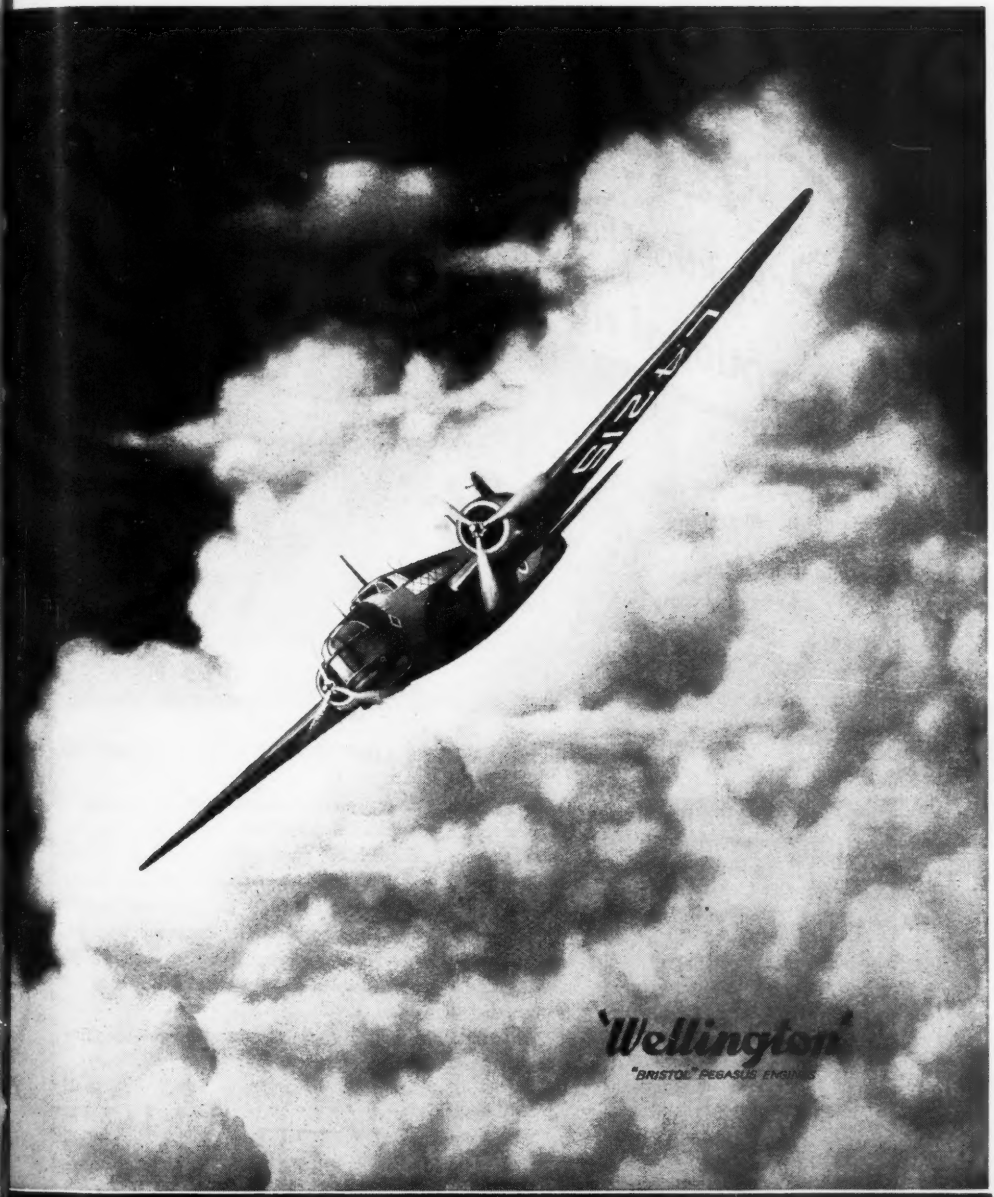

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	3/8 full	48	67,000
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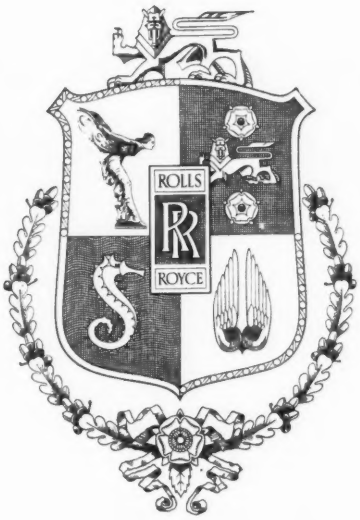

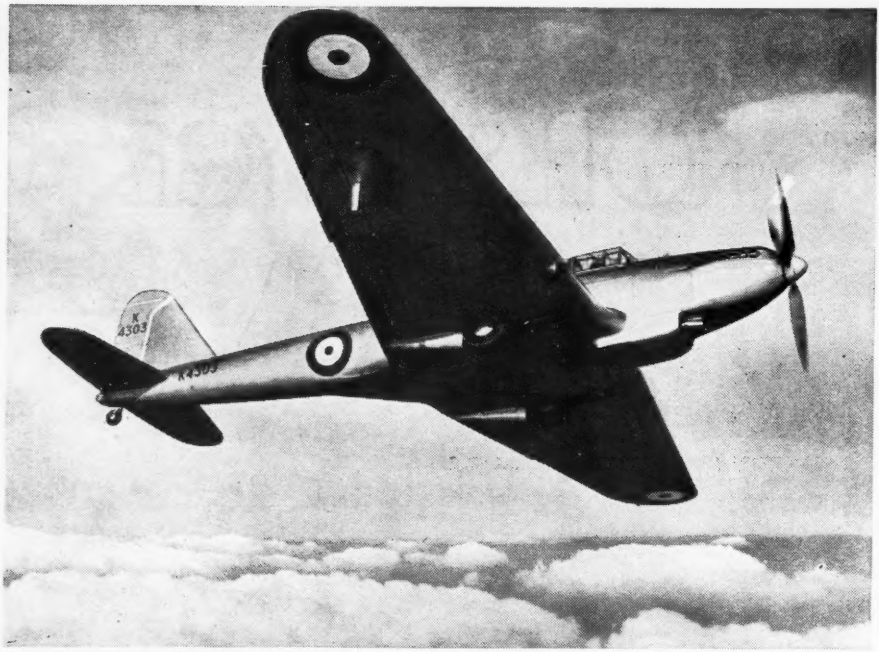

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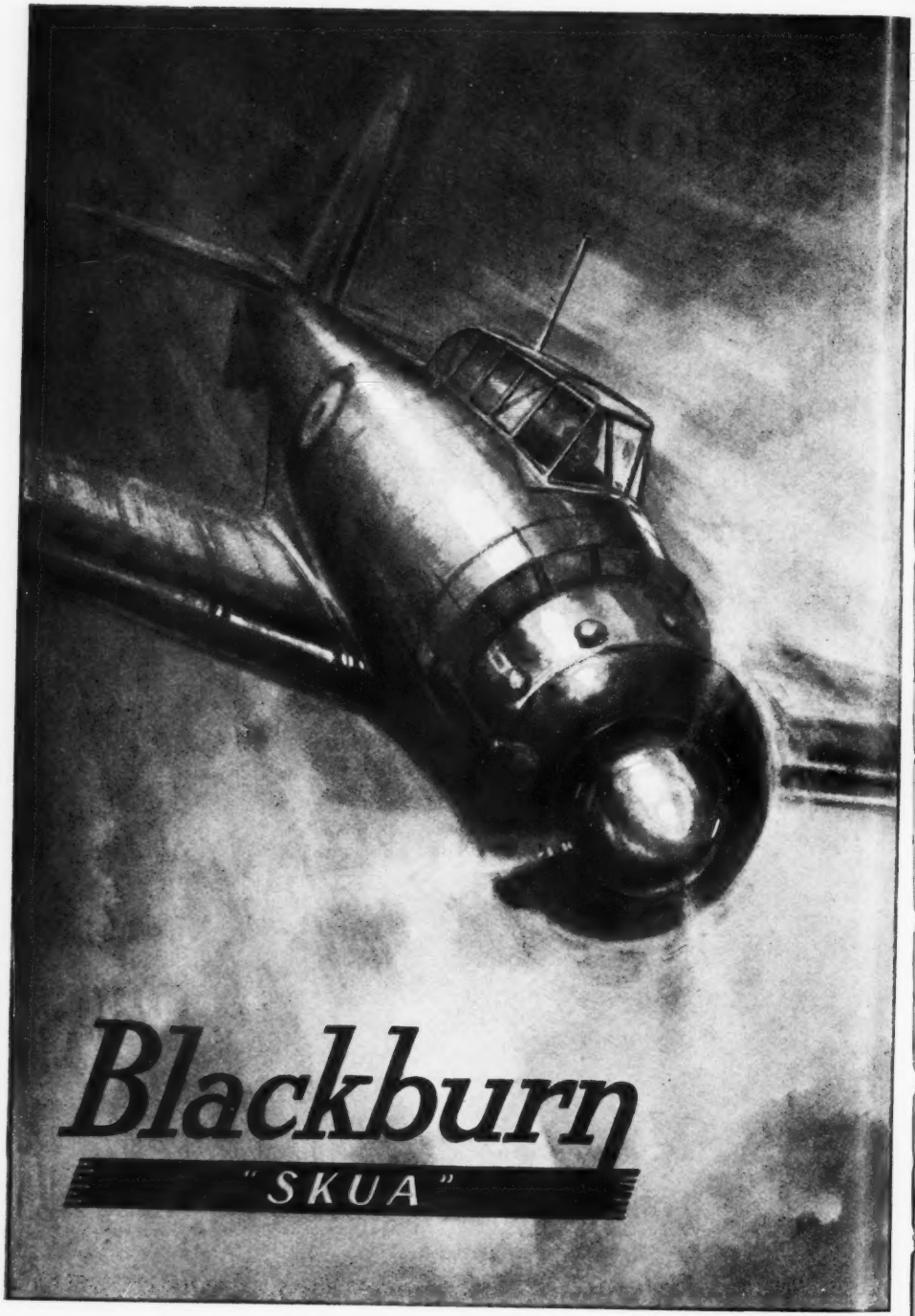
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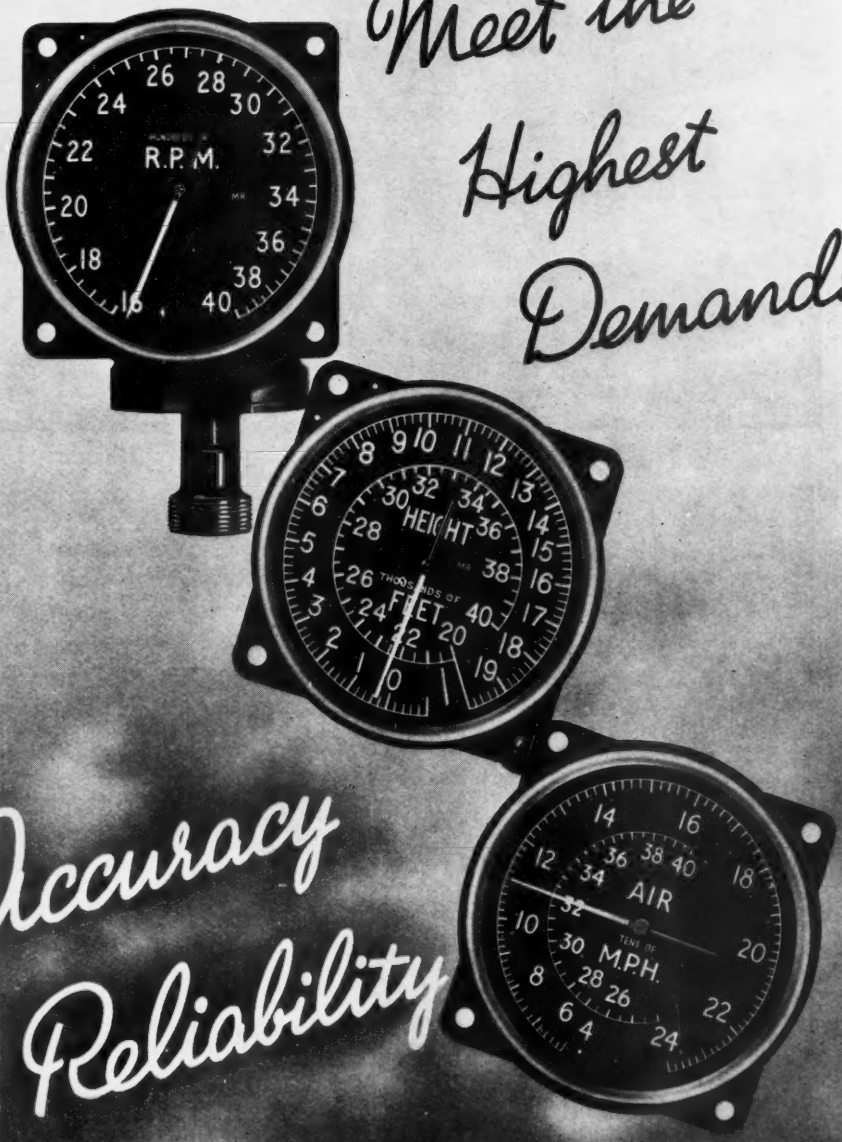

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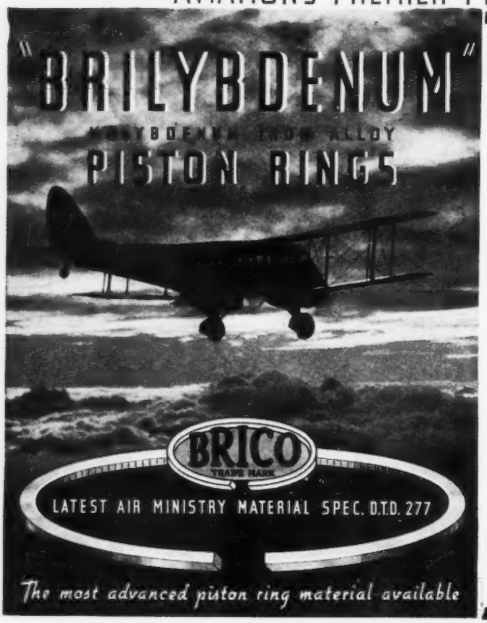

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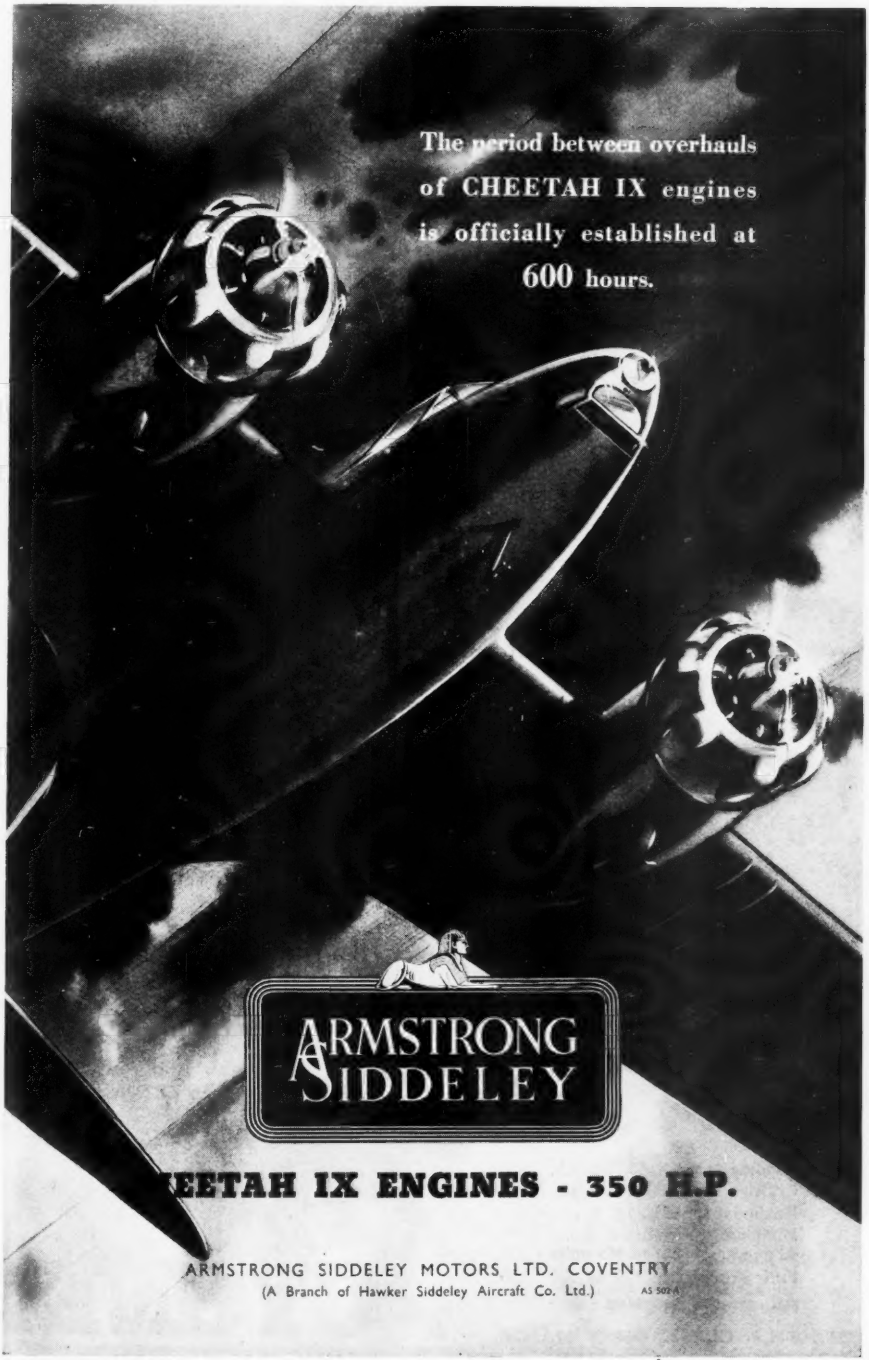
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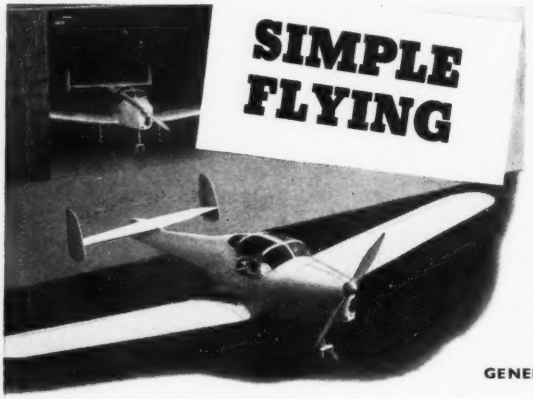

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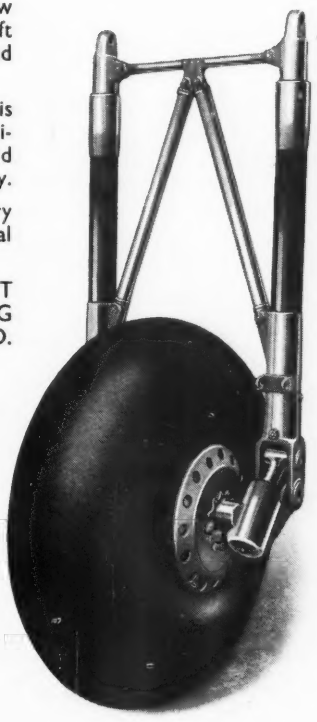

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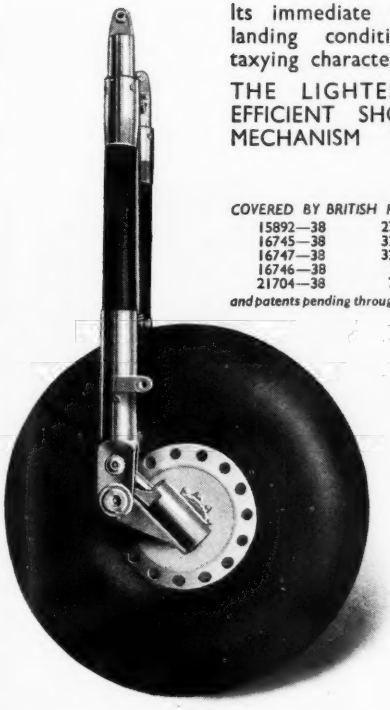

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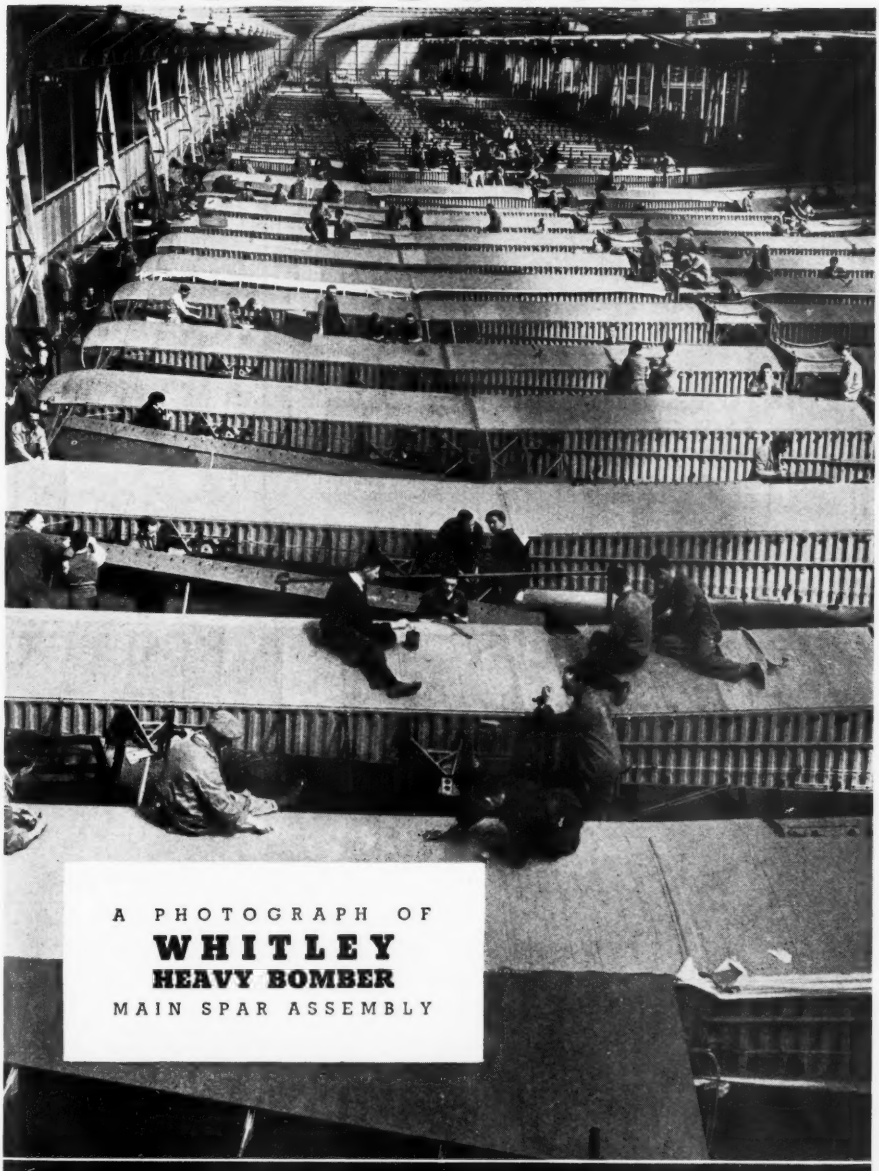

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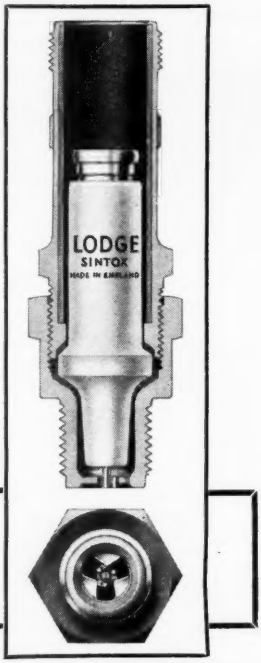

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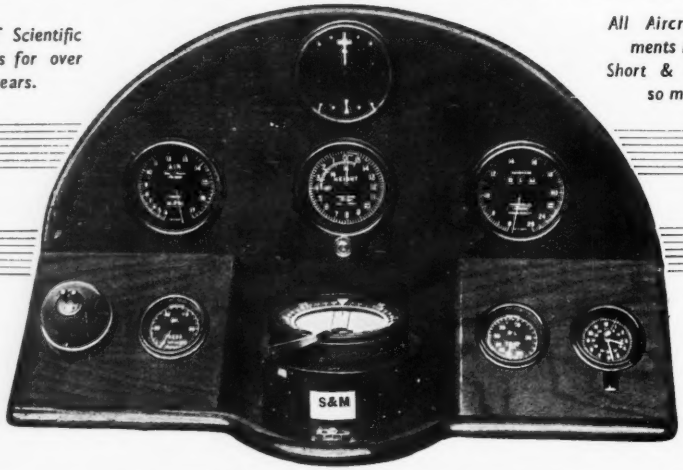

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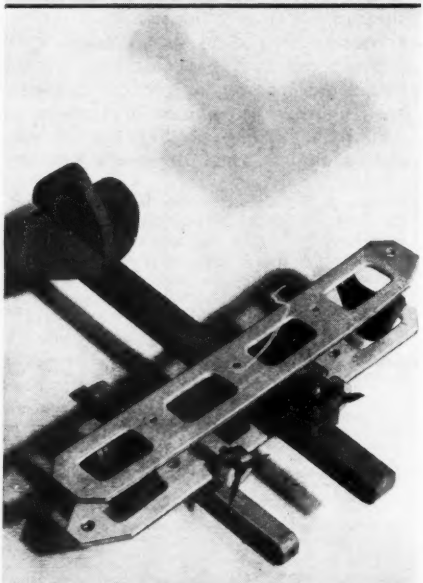

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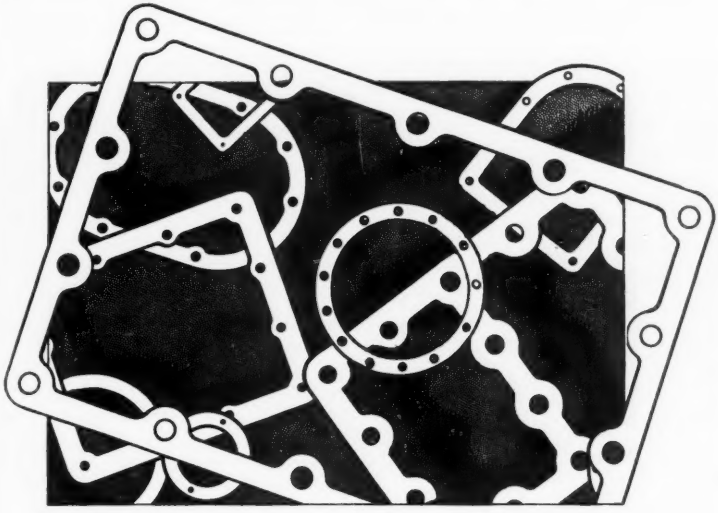

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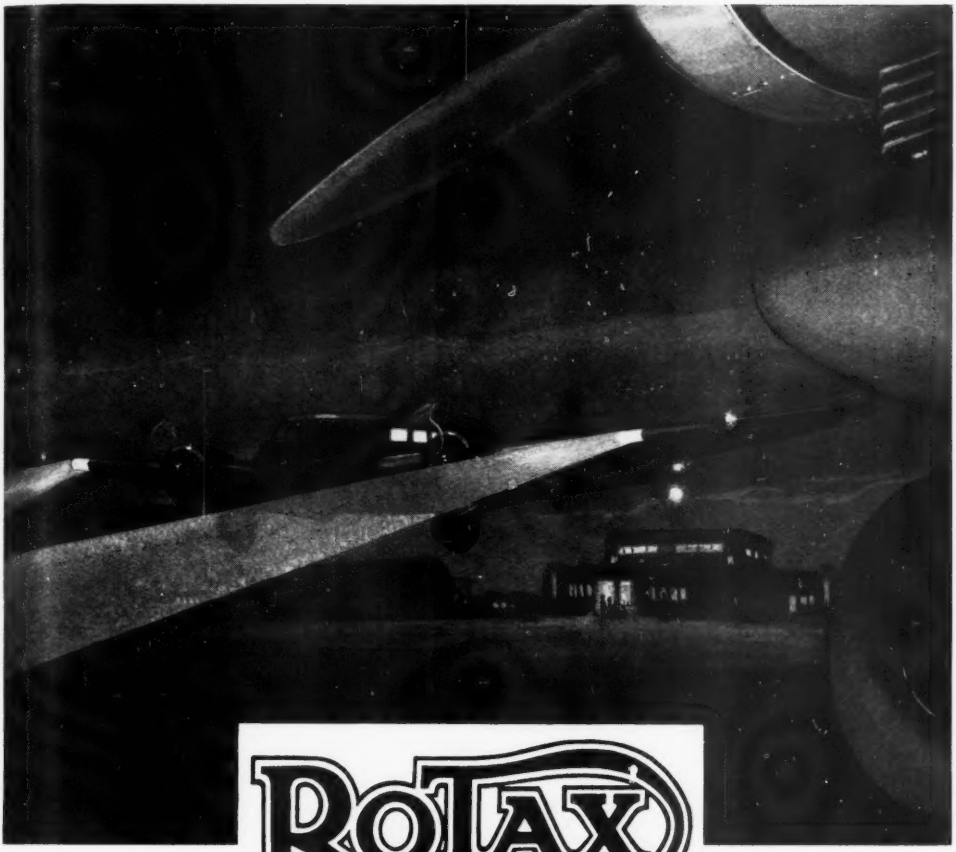

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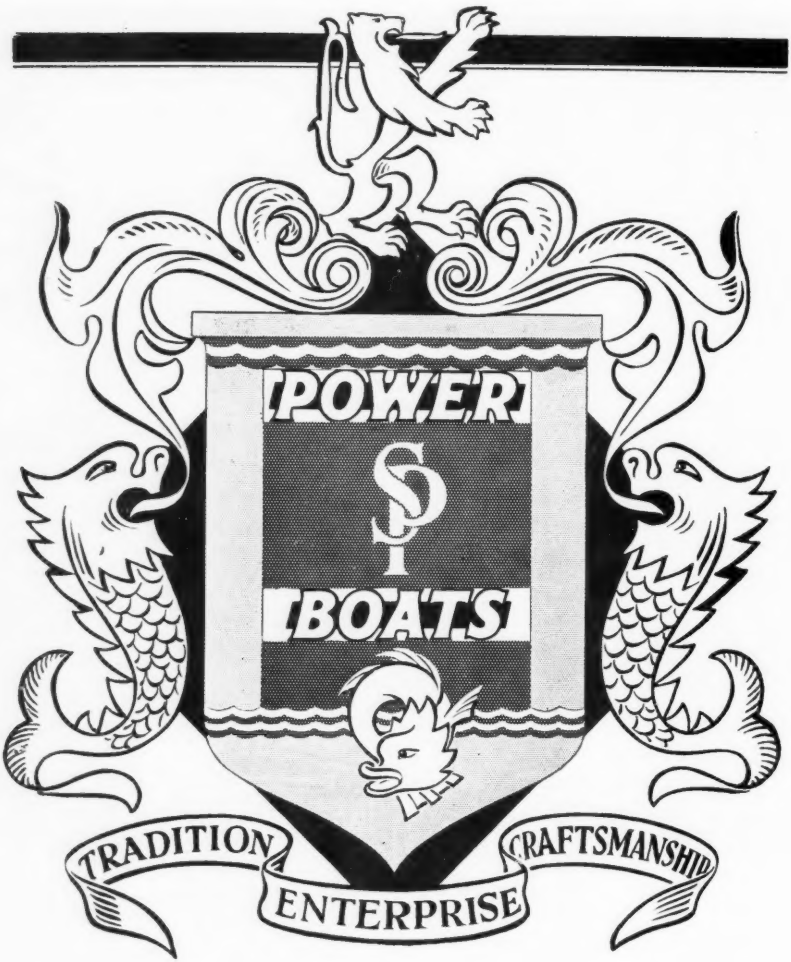

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THE JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY *was founded in* 1897 *in succession to the* ANNUAL REPORTS.

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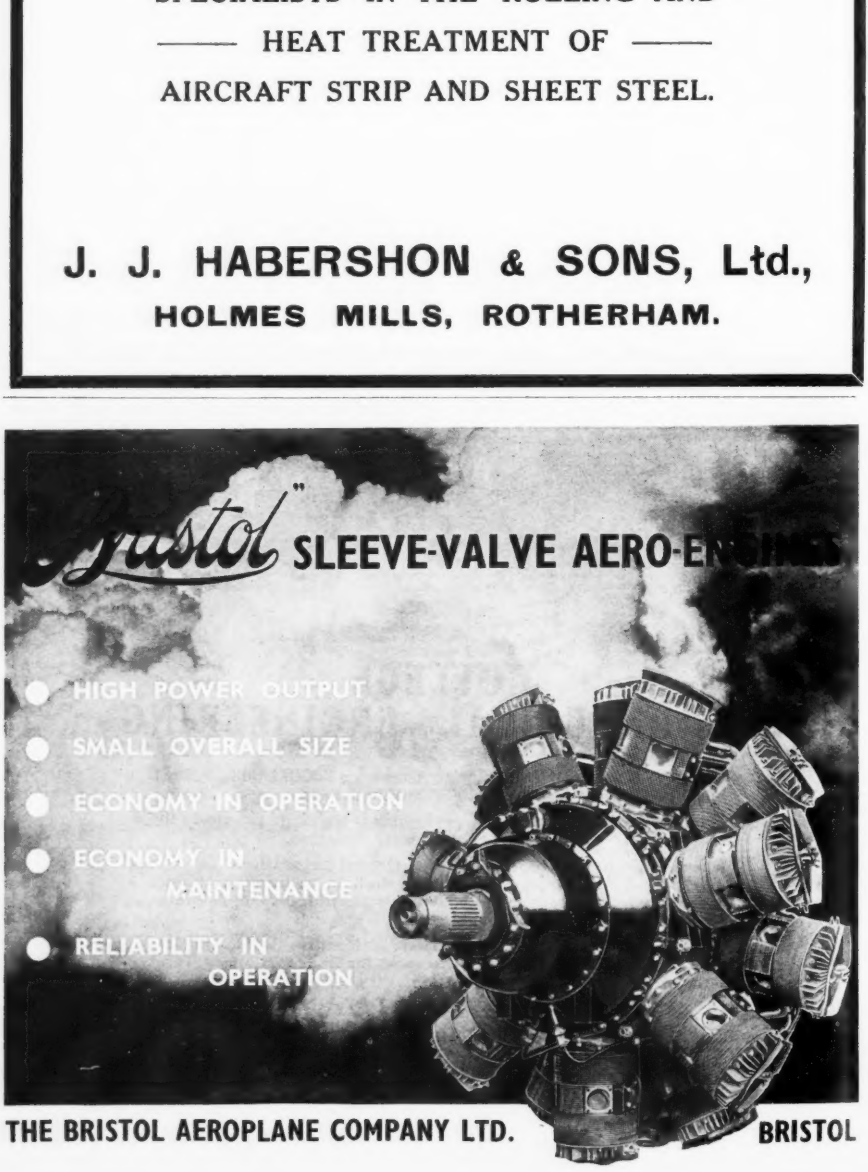

The 640th Lecture to be read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A meeting of the Society was held at the Institution of Mechanical Engineers, Storey's Gate, London, on Thursday, December 15th, 1938, when a paper on "Results from the Deutsche Forschungsanstalt für Segelflug Smoke Tunnel" was presented by Mr. A. Lippisch, A.F.R.Ae.S.

In the chair: Lord Sempill, A.F.C. (Fellow).

The CHAIRMAN: The name of the lecturer that evening—Mr. A. Lippisch—was well known to all those present. Some had the privilege of his personal acquaintance, and he, himself, was proud to class himself as one of those, having known Mr. Lippisch for nearly 20 years. Mr. Lippisch had been responsible since 1921 for, one might say without fear of contradiction, the world development situation in motorless flight. In 1918 he was concerned with the power plane development of the Dornier organisation, but in 1921 he took up the development of sail-planes of different types and the development of the early types and also the later types had emanated from the brain of Mr. Lippisch. Therefore, his contribution to motorless flying throughout the world had been very considerable, and the Society was specially fortunate in being able to welcome him. The lecture which Mr. Lippisch was to give would illustrate some of the most remarkable films that had ever been seen in England or anywhere else with regard to these specific matters. Further, Mr. Lippisch had had a great deal to do with the development of the tailless aeroplane and it might not be long before something would be heard of his very remarkable and interesting experiments on wing flapping machines. He therefore asked that Mr. Lippisch should be given a cordial welcome for all he had achieved and also because they in this country owed him a great deal inasmuch as when the sail-plane movement was started here some eight years ago it was the research organisation with which Mr. Lippisch was concerned which sent over here Herr Magersuppe and others to help. The technical data was supplied by Mr. Lippisch and therefore they owed him a great debt of gratitude which he knew they would all express by the cordiality of the welcome they would give to Mr. Lippisch.

RESULTS FROM THE DEUTSCHE FORSCHUNGSANSTALT FUR SEGELFLUG SMOKE TUNNEL.

By A. LIPPISCH, A.F.R.Ae.S.

Aerodynamics is one of the main fields of application for practical mathematics and the treatment of aerodynamic problems requires a thorough mathematical training. Whoever opens a modern book on aerodynamics will be surprised from the very beginning, that the phenomena within this very fugitive medium air may be expressed by formulas according to mathematical laws.

We must, however, never forget, that before a flow phenomenon can be mathematically analysed, physical reality must be understood by observation and experiment.

The mathematical treatment will always tend towards an approximate solution, as it is much too complicated to analyse a flow process exactly. The approximation must, however, have been aimed at before the mathematical treatment is

begun, by determining from observation the essential characteristics and neglecting the secondary influences. By the adoption of a symbol embodying the important characteristics, the physical process is prepared for the analysis.

So far as we are considering a purely mathematical problem it will not always be necessary to refer to physical reality. If, however, a physical process is mathematically represented, this is quite indispensable.

When considering aerodynamic problems especially, we can only successfully carry out the mathematical treatment, if we have a clear understanding of the physical process.

A classical example of this kind is the aerofoil theory created by L. Prandtl. The exact treatment would require the representation of the wing by a vortex body. Up to the present date this problem has not been satisfactorily solved. The supporting vortex filament, on the other hand, which was adopted in place of the body makes it possible to represent all the important aerofoil problems in spite of this apparently very rough approximation, as the substitution possesses all the essential characteristics influencing the flow configuration about the aerofoil.

The rapid progress of aircraft development calls for the treatment of a great number of new aerodynamic problems. The purely mathematical treatment encounters some difficulties as it is almost impossible to separate in the course of the mathematical analysis the influences which are physically essential and those which are negligible.

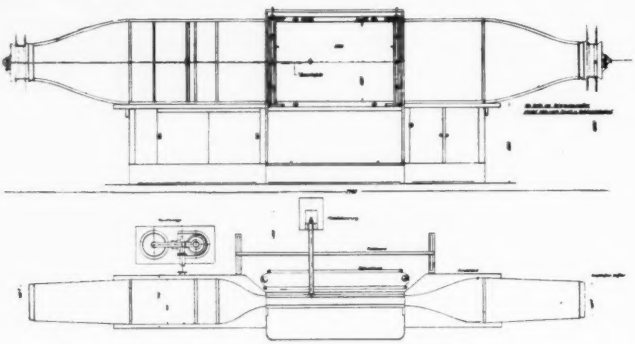

FIG. 1.

Side elevation and plan view of the smoke tunnel.

The airflow cannot be seen by the eye and by force measurements alone the flow process is not thoroughly understood. It was therefore our primary task to develop an instrument which enables us to render visible different types of airflow.

The smoke tunnel, which was built in the D.F.S., renders it possible to visualise all the phenomena occurring in two-dimensional flow.

Attempts to render the airflow visible by means of the introduction of smoke have already been undertaken from different sides. Hitherto one had, however, only succeeded in maintaining the smoke filaments for very short distances and therefore a number of different methods have been employed to reach better visibility for larger distances. The best method which, as far as I know, was first realised in England consists in leading hot wires through the flow giving rise to the formation of warm air layers.* In this respect the work of Mr. Townend is of special importance as work well known to you.

* By illuminating the flow by means of a spotlike source of light flow pictures are obtained due to the formation of the Schlieren.

When designing the smoke tunnel I mainly intended to render the field of flow visible in all its details and to give it a form, which makes it possible to demonstrate certain flow configurations to a larger audience. I therefore designed a normal wind tunnel of extremely narrow cross-section of rectangular form. The test section is closed by glass panes (Fig. 1).

The air is sucked by a blower at the end of the tunnel. At the entrance to the test section a tranquilising room is provided and close to the test section a cone of high convergence (1 : 10). After numerous experiments I came to the conclusion that the smoke must be blown into the cone through long tubes at the point of greatest velocity increase, meaning greatest pressure decrease. At this point the flow possesses the least tendency to become turbulent and one is able to blow the smoke into the accelerated flow without vorticity. If provision is made to keep the air flowing through the test section free from turbulence, the smoke filaments moving with the flow will not be disturbed.

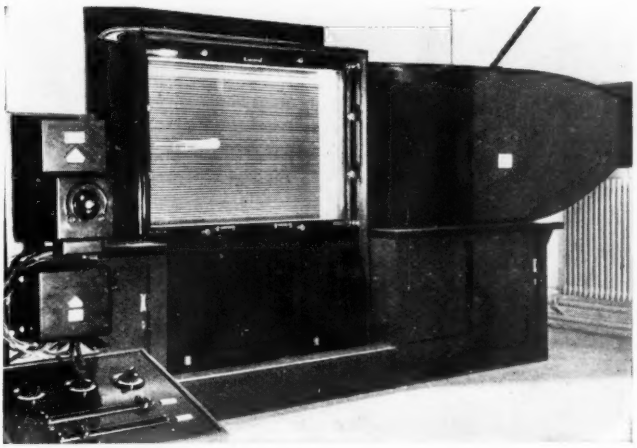

FIG. 2.

General view of the smoke tunnel.

To make the air free from turbulence, several wire nets with very close meshes are provided outside the entrance cone, making the air approaching with different velocity micro-turbulent and eliminating the larger velocity differences. Normal rectifiers are not sufficient to produce a really uniform air flow. The nets, of course, give rise to a very considerable power loss. Due to the small cross-section of the jet the power required for accelerating the air to normal velocity is nevertheless relatively small. By blowing the smoke into the uniform jet at the point of greatest acceleration it is therefore possible to obtain clear smoke filaments over longer distances, which in our case extended over a field 3.3 ft. in height and 4.9 ft. in length (1 m. by 1.50 m.).

There is no difficulty in producing smoke filaments of greater length according to the same method, and by suitably designed entrance cones these filaments may be maintained at higher jet velocities.

This only requires a higher convergence of the cone. Of course much experimental detail work requiring great patience is necessary as small inaccuracies or leaks in the tunnel wall have considerable influence on the smoke filaments. One must not lose patience if such faults cannot be found for whole days.

As further increase in wind velocity gave rise to considerable depression within the tunnel, a second blower was provided at the entrance cone. By this arrangement any desired pressure could be obtained in the test section. The highest velocity which was obtained up to this date in the tunnel amounted to 82 ft./sec. Normally a velocity from 26 to 33 ft./sec. is employed, as with high velocities the process cannot be fully observed by the eye. In the back glass pane the suspension of the models is installed. Three different controls fitted into each other are provided: Control of the angle of attack, of different flap deflections or other movements. The controls are fitted into a tube and are hidden from the observer by the model. The control of the model can be operated, during observation, from the front of the tunnel. The smoke is obtained from rotted wood by means of a specially designed smoke-stove. The smoke is led through a coke filter and is water-cooled, so that all greater particles and the tar distillates are eliminated. This cleansing of the smoke is indispensable as the inlet pipes would otherwise be quickly clogged.

From a central tube in the cone the smoke is led into small aluminium tubes. The smoke is delivered by a special blower. This blower is adjustable according to the wind velocity. In order to determine the velocity conditions at a certain flow configuration an arrangement has been provided to deliver the smoke periodically. In this way different smoke fronts are formed, the deformation of which gives us an insight into the velocity distribution. We call it "intermittent smoke delivery." Fig. 2 shows a general view of the smoke tunnel. By a strong lateral illumination the smoke lines become clearly visible against the dark background. A special illumination by means of arc lamps has been developed for the slow-motion pictures which I am going to show you afterwards, and which have been obtained at exposures of less than 1/1,000 sec. (Figs. 3, 4, 5 and 6 are extracts from the film, and show the flow phenomena occasioned by various models suspended in the smoke tunnel.)

In order to obtain a better insight into the characteristics of the tunnel, comparative pressure distribution measurements have been carried out for a number of N.A.C.A. sections. The slope of the lift curve without applying any corrections amounts to

$$dc_1/d\alpha = 5.91.$$

This slope is therefore somewhat less than the slope of pure dimensional flow. The moments are in good agreement with the results from other tunnels. There is also agreement regarding the incidence at zero lift. The tunnel is therefore not only employed for carrying out flow observations, but there have also been carried out a number of very satisfactory pressure distribution measurements.

For the purpose of flow demonstration the models possess a depth from 40 to 50 cm. (14 inches to 19 inches). The width of the tunnel amounts to 2 inches and with the newer realisations to 2.8 inches. Pressure distribution measurements have shown that the visualised flow configurations agree with the flow in the free atmosphere, so that the experience obtained from experiment is applicable to actual conditions in the usual way. We must naturally bear in mind that, due to the limitation of the field of flow in the smoke tunnel, a parallel flow is brought about at the boundary, so that the flow representation is reduced in height compared to the full-scale conditions.

The value of the smoke tunnel consists chiefly in demonstrating the effects of a given body on the flow and to show the true course of flow in the case of special devices. Without carrying out tedious force measurements we are therefore in a position to develop aerodynamically good designs or to observe a special flow phenomenon which enables us, for instance, to determine the true causes of stalling effects.

The rapid development of aerodynamic science demands the investigation of the field of flow for preparing the theoretical treatment of a number of new problems. In these cases force measurements alone are not sufficient to give an

insight into the real flow phenomena and to draw conclusions regarding the improvement of given devices.

On the other hand, periodic flow can be specially well observed in its development with time. On the whole, we may say that the smoke tunnel offers a great number of possibilities and the following pictures will show that this kind of flow investigation is capable of furthering our knowledge to a very high degree.

The following pictures were obtained in the D.F.S. The parts of the film that were shot at normal frequency have been obtained by the " Movikon " of Zeiss-Ikon. Due to the kind assistance of Zeiss-Ikon I was then in the position to obtain a number of specially interesting flow pictures by means of the new slow-motion camera employing 16 mm. film. This camera gives a continuous film delivery up to a velocity of about 100 ft./sec. (30 m./sec.). The pictures are projected on to the film by a coupled mirror ring.

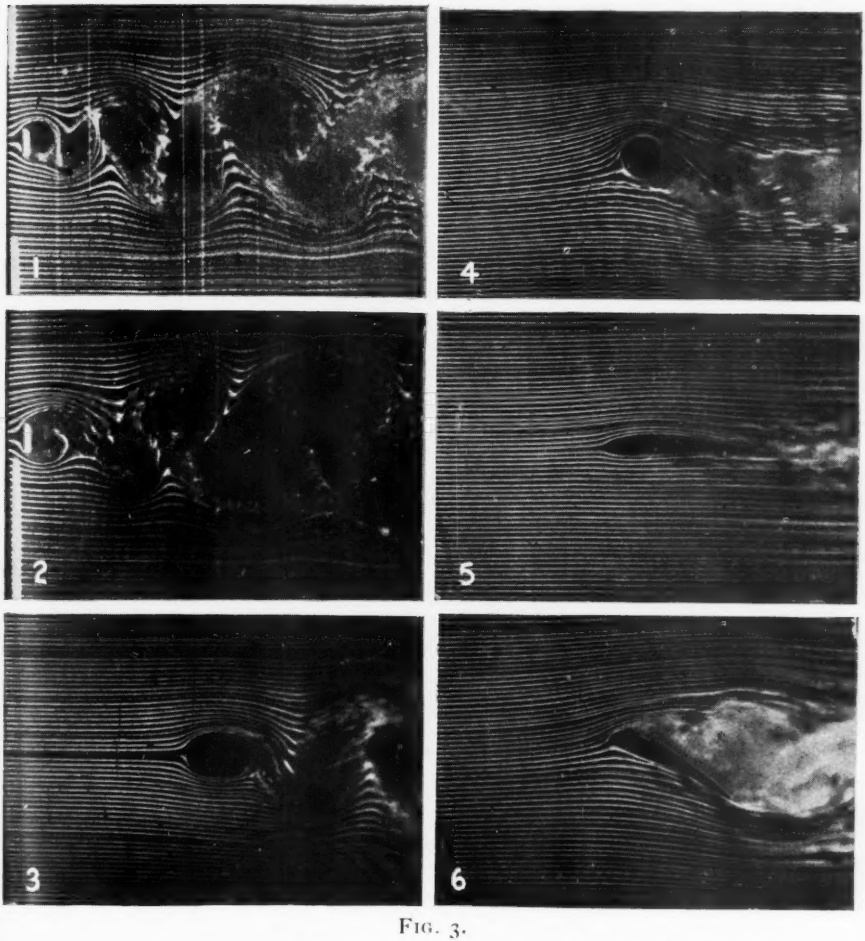

FIG. 3.

1 } Eddies behind a flat plate.
2 }
3 Eddies behind a fixed cylinder.
4 Magnus effect of rotating cylinder.
5 Flow past aerofoil at zero angle of attack.
6 Flow past stalled aerofoil.

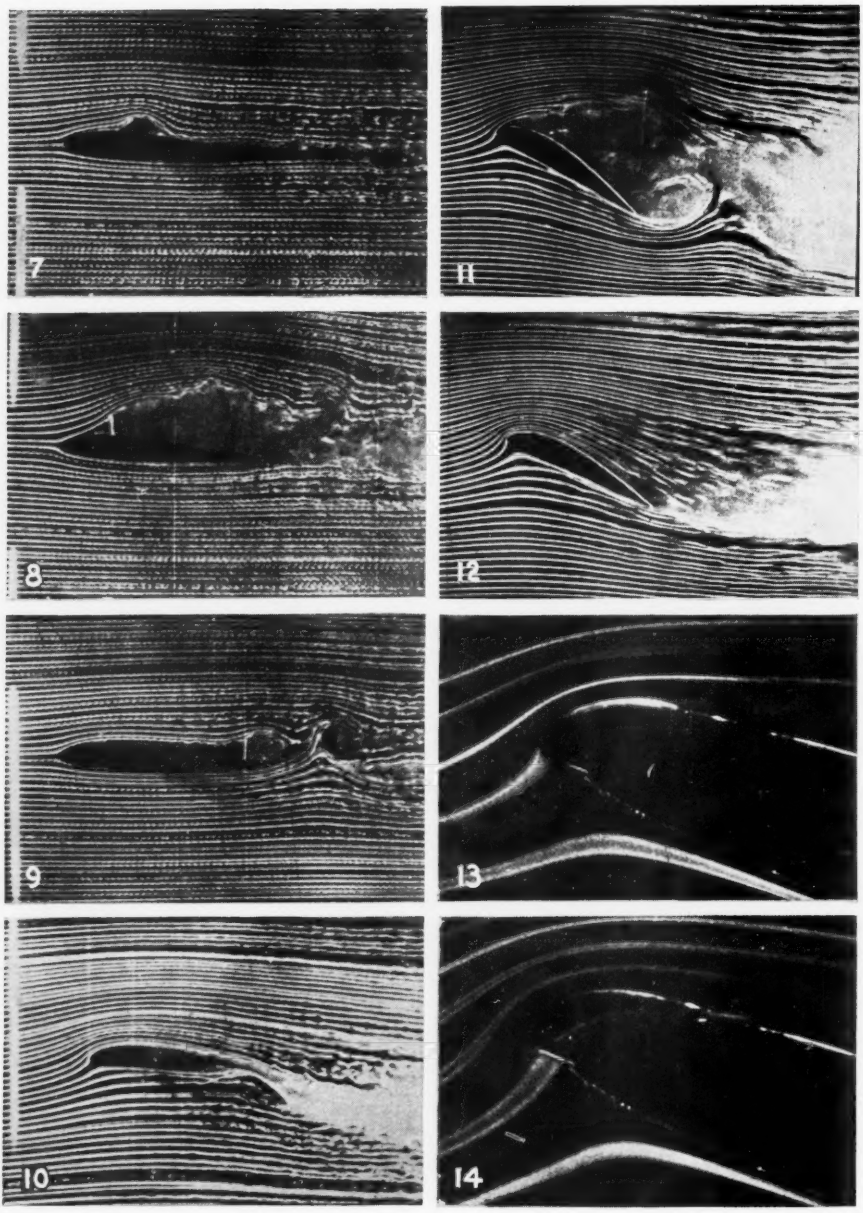

FIG. 4.

7 Lift first increased by raising spoiler flap.
8 Lift finally destroyed by spoiler.
9 Spoiler flap at trailing edge (drag increased, lift unaffected).
10 Effect of Fowler flap.
11 Aerofoil well stalled.
12 Boundary layer suction applied to 11.
13 Flow with slot slightly open.
14 Flow with slot fully open.

Up to a frequency of 1,000/sec. the film delivery is by clockwork. The camera may therefore be used anywhere. When the clockwork is fully wound up about 65ft. of film (20 m.) are delivered within a few seconds. What can be observed happening slowly, in reality takes place within fractions of a second. Normally the film is shown at a velocity of 16 pictures/sec. The frequency of the slow motion pictures is 1,000/sec. The process is therefore slowed up 60 times.

The first part of the film shows the known flow phenomena behind a vertical plate, a circular cylinder and some extensions of these elementary flows, flow about a rotating circular cylinder and a vertical plate which is caused to rotate by the air stream.

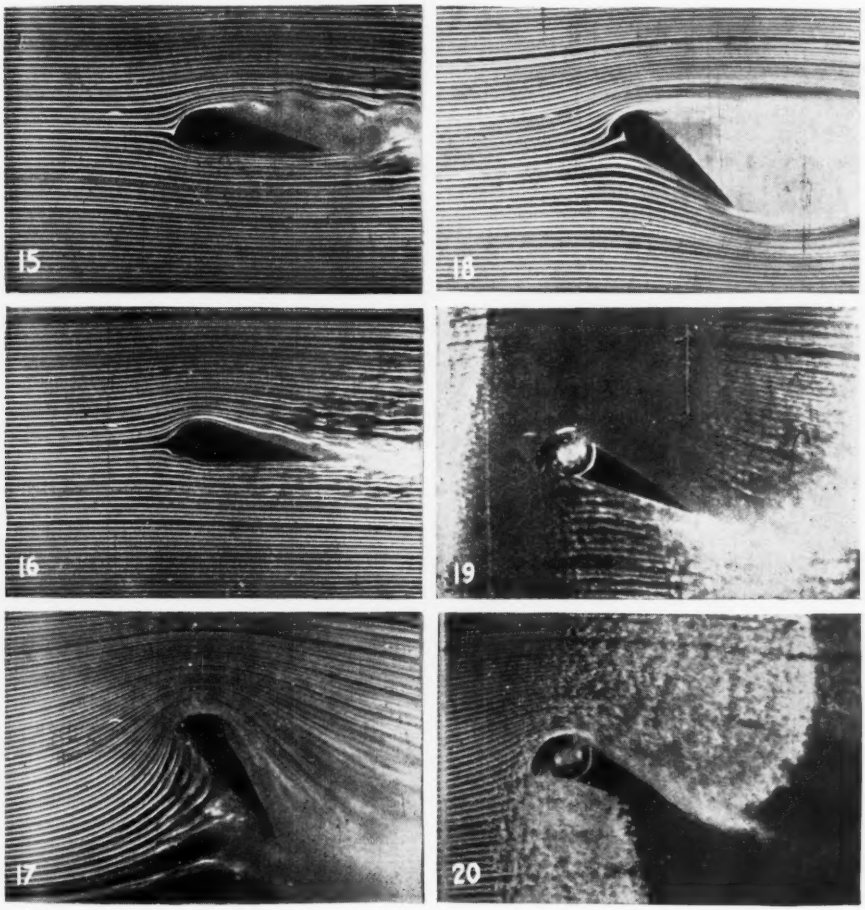

FIG. 5.

15 Eddy behind Lippisch rotor-wing with rotor stationary.
16 The same with rotor working.
17 Rotor working, angle of attack about 70°.
18 Rotor stationary, high incidence.
19, 20 Acceleration of flow over upper surface shown by slow-motion photography of intermittent smoke delivery.

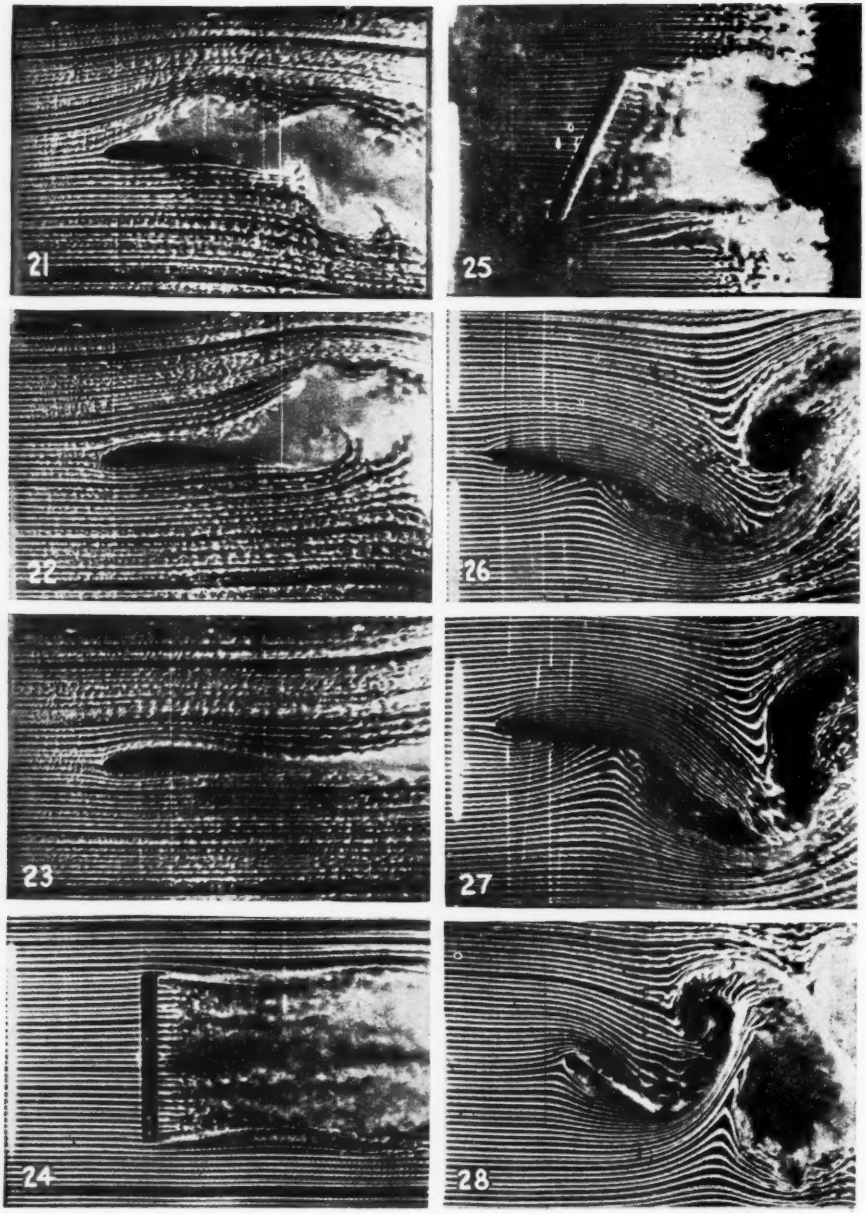

FIG. 6.

21, 22, 23 } Showing how eddies die away with decrease of incidence from stalling to no-lift.
24 Three-dimensional flow about an aerofoil. (Note wing-tip vortices, and retardation due to frictional drag.)
25 Flow over a yawed aerofoil.
26, 27 } Flow behind a rigid flapping wing.
28 Flow behind a flapping wing with flexible trailing edge.

I am going to show, in the first place, the formation of the Kármán street behind the vertical plate and the circular cylinder. I want to call your attention to the fact that by these pictures the cause of the periodic detachment of vortices is made visible. Up to this time the Kármán street has only been observed in water mainly by v. Kármán. Hitherto it has not been possible to show these things in the air stream and it will be an interesting investigation to compare the flow pictures obtained by us with the pictures of the same kind in the water stream.

In order to make the formation of the vortex street behind the body easily understood, some of the pictures have been obtained with intermittent smoke delivery. It is most interesting to observe the velocity distribution when a smoke front passes through the field of flow. When the initially straight front approaches the vertical plate or the cylinder a marked velocity decrease may be observed in front of the body. I want to draw your attention to another most interesting fact which consists in the periodic displacement of the stagnation point on the front side of the body which is caused by the periodic detachment of the vortices. In general one is surprised when seeing how far the influence of a small body extends itself in the vertical direction. Without this visualisation one always tends to suppose that the disturbed area has approximately the same dimensions as the body itself in the vertical direction. In fact the disturbed area is many times greater than the height of the experimental body. The interpretation of these pictures allows us to obtain an estimate of the drag of the body in so far as it can be derived from the energy contained in the vortex street, similar to the investigation by v. Kármán. This demonstration of flow enables us as well to determine the detachment of vortices in relation to the wind velocity.

Towards the end of the film I show a number of pictures of the rotating circular cylinder for demonstration of the Magnus effect, *i.e.*, the creation of lift circulation. You will see that in this case the separation of flow no longer takes place in the form of a Kármán street, but that an ordinary dead water region forms itself behind the body. If the number of rotations is low the energy lost in the wake of the circular cylinder is smaller than in the case of the normal cylinder. This explains why a marked decrease of drag is contained in the polar diagram of the rotating circular cylinder at small values of u/v. At the rotating cylinder the flow merely separates from the lower surface of the body.

At the end of the film I show a rotating flat plate which is brought into movement by the air stream. In this instance a certain amount of lift is also brought about, though it is relatively small. The pictures make it clear that the detachment of flow only takes place following a potential flow with unduly high velocities at certain edges of the body.

The second part of the film contains flow configurations of the aerofoil section and the aerofoil itself. The slow motion pictures show with a clearness which has not been reached before, the lag of the stalling effect occurring when the incidence is suddenly increased. If the incidence is changed at short intervals high lift may be obtained without stalling of the flow. It is undoubtedly possible that in the case of a rapid periodic change of incidence no stalling will take place in spite of great effective incidences. This condition, which is mainly determined by the value of the angle of attack, the wind velocity and the depth of the profile may be defined by systematic experiment in the smoke tunnel.

The third part of the film shows that this phenomenon is specially important for determining the real causes of the effect of the flapping aerofoil.

It is known that retardation effects also take place when flaps are deflected. This is demonstrated for the Fowler flap, as the deflection of such a flap leads to a very considerable change of the lift-producing flow, so that the lag is clearly to be discerned.

I show a number of further devices for the increase of lift. I want to draw your attention specially to the combination of rotor and aerofoil which I have developed and which are being shown for the first time. Originally this rotor wing inspired me to design the smoke tunnel as I wanted to investigate in what way the flow is influenced by the installation of the rotor. It will be seen how it is possible to maintain lift up to incidences of nearly 90° by means of mechanical devices which are still in the range of the possibilities of technical realisation. By the intermittent smoke delivery the great velocity differences between the upper and lower surface in consequence of the very strong circulation are shown.

This second part would, however, not be complete if I could not render visible flow configurations of the three-dimensional type.

It is, of course, rather bold to mount an aerofoil into the narrow channel in order to demonstrate the formation of the marginal vortices and the retardation of flow due to the frictional drag on the surface of the wing. These pictures may therefore only be considered as an approximate demonstration of the process as the small depth of the channel forbids the extension of the flow configuration upward and downward.

In this case also the demonstration gives an impressive picture of the physical process.

The sudden increase of incidence has also been obtained for the flow about the whole aerofoil and the retardation effect can be clearly discerned.

The pictures of the yawed aerofoil make visible the unequal strength of the marginal vortices in consequence of the unsymmetrical lift distribution on the yawing aerofoil. Besides a marked bending of the streamlines passing over the surface may be discerned. This bending effect must be taken into account by the calculation of the lift distribution on the yawing aerofoil and it will be at once obvious that the attempts made hitherto to determine the lift distribution over the yawing aerofoil by means of the conception of the supporting vortex filament had to fail, as the physical phenomenon was not taken into consideration by the mathematical symbol.

In the third part of the film flow configurations on periodically moved aerofoils are demonstrated.

The problems dealt with here are of the greatest interest due to the importance of the aerodynamic process as regards aerofoil oscillations. A number of known research workers have already carried out considerable work of a theoretical nature on these problems. Experimental investigation in this field is, however, very scarce, and I consider the following pictures a contribution to experimental research about the aerofoil oscillations.

Quite new flow configurations may be seen and only after some time can we learn to understand the mechanism of these flow configurations and to interpret it.

I am convinced that we will only then obtain full insight into these problems which are of vital interest for aircraft construction, if by observation and systematic research we have understood the flow process as a physical phenomenon and not as a mathematical formula.

Of course I can show but very rudimentary examples of these flow problems as it is only a few months ago I had the opportunity to visualise periodic flow by means of the slow motion camera.

A new field of research offers itself to the investigator and a great amount of new material must still be gathered until a relatively complete demonstration of periodic flow problems may be reached.

Besides there is another problem of aircraft technique which has hitherto been very much neglected—the problem of flapping flight.

The smoke tunnel and the slow motion camera show us most interesting demonstrations regarding this problem. The flow visualisation explains to us, why Nature has provided all the flying creatures with those soft elastic wings. I will not here enter into a description of the aerodynamically favourable design

of the wings of birds, but I want at least to point out that the elastic trailing edge characterising all the wings of flying creatures is connected with the necessity of obtaining practical simultaneous changes of incidence and lift. This requires, however, the formation of starting vortices which are indispensable for the formation of lift changes. At the rigid trailing edge and in general on the rigid wing the formation of these starting vortices is realised considerably slower than with the elastic trailing edge, which adjusts itself to the direction demanded by the starting vortex. After a thorough study of these problems in the smoke tunnel I immediately succeeded in building flying models with flapping aerofoils giving satisfactory performances.

In this instance, comprehension of the problem has been furthered by the clear visualisation of the physical process and I hope that besides giving you some suggestions for your own research work, I have proved to you that it is of high scientific value to render visible flow phenomena occurring in the air stream.

Formulas serve the calculation. A physical phenomenon will only be understood if it is visualised close to reality. What impresses itself to the eye will not remain incomprehensible to the mind.

Discussion.

The Chairman: It was not his purpose to take from those who would participate in the discussion, those words of just admiration which they would wish to express to the lecturer for his lecture and the films, but he nevertheless wished, on behalf of all those present, to compliment Mr. Lippisch on his brilliant delivery of the lecture in a language which was not his own. Most of those in the room would be only too pleased if they had 50 per cent. of the 100 per cent. efficiency which Mr. Lippisch had in that respect. Perhaps it would be appropriate if Mr. Lippisch replied fully in writing to the discussion on his lecture, but he might be able to answer briefly some of the points which would be raised.

In calling upon Prof. G. T. R. Hill to open the discussion, the Chairman said that Prof. Hill was Kennedy Professor of Engineering in London University. He had been over to Germany on many occasions and had worked in collaboration with Mr. Lippisch, and was familiar with the working of the smoke tunnel which had been described. Therefore he could speak from first hand knowledge on all that they had just heard and seen.

Prof. G. T. R. Hill, M.C. (*Fellow*): The author spoke as an engineer. They had heard how he designed gliders and aeroplanes besides such things as wind tunnels, and after seeing the film it appeared that he could turn out something pretty good in the way of a new kind of zebra! What was to be learned from the films which the author had shown? As the author himself had said, with the help of such films, thought was given a start in the right direction. In other words, it helped to avoid the setting up of a false and unreal hypothesis, and using it to build up a wonderful mathematical theory which gave a wrong answer. The author himself had expressed that view very clearly and it was a point which must be taken to heart by them all.

After seeing pictures like those shown by the author, one wanted to go away and think about them for a while, and speculate upon the implications which were involved. Personally, he had had an opportunity of doing that, having seen these films for the first time on the previous evening, he asked them to try and imagine what happened to, say, the tail plane of an ordinary aeroplane at stalling incidence. Let them think of those tremendous waves hitting the unfortunate tail; the wonder was not that there was tail buffeting, but that the tail did not fall off every time an aeroplane stalled. Then there was the picture with what looked like a little "water wheel" in the front of the wing section which seemed to lift quite happily at nearly 90 deg. incidence. In the present state of the art it would take the most skilful pilots in either England or Germany to land a machine with such a wing, but we may in the future learn to use the principle.

Another example of the way use could be made of the kind of picture the author had shown was in the study of boundary layer suction. It was possible actually to see where the air went as it rushed inside and was sucked away. Surely that was going to make far easier the task of positioning the slots so as to arrive at a high over-all lift coefficient?

Then was the question of the lag that was shown when spoilers were operated. In that case it was possible to see how the air flow did not respond instantaneously to the change of the wing shape, but that an appreciable time had to elapse before the new flow was established. The fact that there was lag had been observed on the full scale, but the exact way in which the flow behaved had been seen in an extremely clear form when the film had been slowed down.

Continuing, Prof. Hill said he would not elaborate these points which had probably occurred to those who had seen the films, but he wished to say that he knew from experience that whatever the author did, he did extremely well. He asked them to look, for instance, at the tunnel and the streams of smoke. He had had the opportunity of going to Germany and seeing the real thing, and actually working the controls and altering the incidence and watching what happened, and he assured them that it was most fascinating. If anyone got the chance of doing that he urged them not to miss it.

He did not know how many of those who were present were brought up on Maxim's book when they were young. There were probably not very many, but Maxim used a smoke system with jets something like the one shown on the films that evening but, of course, with nothing like the knowledge which it was now possible to bring to bear on the problem. The smoke jets seen in the author's films were very straight and steady, and in the actual tunnel they looked practically like rods of white steel; indeed, they were so steady that it was difficult to believe they were only jets.

There was one question he would like to ask the author. Although this smoke tunnel worked with a Reynolds number very much higher than that of any smoke tunnel he had heard of before, with speeds of 8oft. per second and several inches chord on the models, they were still far below full-scale conditions. Would the author explain how he related the observations at the model Reynolds number to the conditions at the full-scale speeds at which aeroplanes fly and stall? In this country it was thought that that was very difficult to do, and if the author could throw any light on the connection between the model and the full-scale, it would be greatly appreciated.

He felt sure everybody would agree with him in his view that the Chairman's remarks were in no way exaggerated when he said, as he introduced the lecturer, that they would be shown a series of pictures which, for interest, beauty and mental stimulation, would excel any shown up to the present in this country or, for that matter, in any other country in the world.

Dr. H. C. H. Townend (*Fellow*): He had not come prepared to discuss the lecture as he had only just been able to read it. He had had a shot at this sort of thing himself and knew something of the difficulties the author must have encountered in regard to the technique. It was said that seeing was believing. Having seen the films he believed; but in the days of his childhood he had been cautioned that one must believe nothing one heard and only half of what one saw, and he rather felt that what Prof. Hill had just said in connection with the Reynolds number had a bearing on this belief. In some of the pictures, even with the small range of Reynolds numbers available, it was possible to see changes which were very important and he would very much like to reinforce the question which Prof. Hill put, that the author would say something about what could be inferred at high Reynolds numbers from what was to be seen at moderate Reynolds numbers. The extreme narrowness of the tunnel also tended to raise doubts about the results.

In reading through the proof of the lecture he had come across what was a new term to him. When the lecturer came to it, however, he left it out, which seemed a pity. This was the word " tranquilising." They had heard of " turbulating;" now they had its counterpart, " tranquilising," which together made an excellent pair, he thought.

In looking at films he felt several times he would have liked the film to be stopped to enable him to ask questions but, of course, that was impossible. They had been given an enormous amount of material in half an hour to digest, but for the moment he could only remember a few of the many things he had seen which he would have liked to discuss. The first thing that had struck him was the fact that, in the airflow past a cylinder, or flat plate at 90°, the air which passed at a distance of about $\frac{1}{8}$ of a diameter from it crossed right over the wake to the other side and usually stayed there for a considerable distance. When he had seen in the proof the reference to slow motion pictures showing the lag in stalling and unstalling of an aerofoil, he had tried to obtain a film which he, himself, had taken at the N.P.L. showing the same kind of phenomenon, but had been unable to do so in time. However, it confirmed what the author had shown and was of interest in connection with some experiments by M. Denis which were reported in the " Comptes Rendus " a few months ago. In these experiments a nominally rigid aerofoil was suspended in a wind tunnel by wires. It was found that at certain wind speeds the aerofoil vibrated in a manner similar to one of the notes in a xylophone, and that when doing so the mean lift coefficient went on rising with the incidence until the experimenters could not carry the experiment any further.

In his own film a further point had been illustrated, namely, that the lag increased with the thickness of the aerofoil. A thin section like R.A.F. 15 had responded to a sudden change of incidence several times more rapidly than a thick one had done.

Towards the end of the paper the author referred to the effect of using a flexible trailing edge to the wings and the pictures showed some very striking results. The feeling one had was that there was a whole lot of evidence available and that it was time someone started inventing something, although he was not quite clear what. Before he saw the film he had intended to ask the lecturer if he could explain a little just what that flexible edge did in the way of helping the vortex to start. Now that he had seen the film and had observed what happened he felt still more mystified, but it was to be hoped that someone would extract something useful from it. Prof. Hill had referred to the use of an aerofoil which did not stall until it got to nearly 90°. Perhaps the lecturer would be able to explain, in this connection, how a fly was able to land on the ceiling.

Mr. W. O. Manning (*Fellow*): He had never seen a better set of photographs on flight in his life. The effect on him had been almost shattering, and he was beginning to wonder whether before that evening they had known very much about the subject at all. Certainly he felt very definitely that his knowledge of the matter as a whole had been very considerably increased in a most extraordinary way in a very short space of time.

Mr. Manning said there were one or two questions he wished to ask. First, with regard to flapping flight and looking at the trailing and flapping aerofoil, one noticed quite a large number of large vortices going off and disappearing into the distance. That seemed to suggest there was a great deal of energy being wasted. He had always been under the impression that the bird, for its size and proportions, was really a fairly efficient flying machine, but if the bird, when flapping its wings, was distributing large vortices of that kind into the atmosphere, it was a little difficult to see how that could be true.

Another point was with regard to the yawed aerofoil. He was wondering to what extent the curious type of flow which had been seen would occur when the aerofoil was swept back symmetrically. He imagined that the curious distortion of

flow in question was due to some distortion of the lifting circulation which would not be possible in the case of a swept-back aerofoil because under these conditions the flows on each side would be symmetrical. However, it would be interesting to know if the curious kink seen would occur in the case of the swept back aerofoil as well as in the case of the yawed aerofoil.

In conclusion, Mr. Manning said he wished again to thank the author for the most wonderful collection of aeronautical films he had ever seen.

Mr. B. S. SHENSTONE (*Associate Fellow*): Like everyone else, he had been greatly impressed by the wonderful photographs which Mr. Lippisch had shown. He believed that the lecturer's first interest in the study of flow started long ago on the Wasserkuppe where he was making sailplanes with a very small staff. There being no money available for a tunnel, he had to wait for a special combination of weather, viz., a high wind and a snow-storm in which to study his flow problems. Fortunately for the lecturer things were now very different financially.

The photographs of the " Kármán street " gave him a new conception. Previously he had thought of the " street " as being comparatively straight with curly edges. Now he realised it was much more extensive and involved, being like a street in a Garden City which went winding and wandering around.

The flapping wing was extraordinarily interesting. He had never seen such a hole as was made in the air by that flapping aerofoil.

The film showed that disturbances extend much higher and farther back than one would imagine. A spoiler sends eddies up two or three times its own height. What must happen behind the many knobs which stick out from any ordinary aeroplane? On this evidence only a fool would put snap (round) rivet-heads on anything which had to be dragged through the air.

Mr. R. KRONFELD (*Associate Fellow*): He congratulated the author on the results which he had been able to produce through experiments in the smoke tunnel. He thought that everybody interested in aircraft design and specially the gliding movement, owed the author many more thanks than could be easily expressed.

He had had the great privilege of working with the author for two to three years, and he could say that Mr. Lippisch was one of the few people who combined the ability of theoretical, scientific thinking with a complete knowledge of practical engineering. Therefore the machines he designed and built were always machines of practical use.

Having seen the film, Mr. Kronfeld said he would like to ask one or two questions. First of all, with regard to the Kármán street, he had watched very carefully the outer wave of that street which moved away at a rather steep angle. Was not that a clear demonstration of the second and subsequent waves which had been experienced on the lee side of ranges of hills by pilots who had carried out long-distance flights and height records on sailplanes in Germany and England?

A second question he wished to ask the author was whether any results had come from the work which was carried out in Germany with machines trying to make use of the " Knoller-Betz " effect.

He remembered as far back as 1931 that he had the opportunity of testing, at Weimar, a flying machine which was specially designed to make use of this effect. He could not get much result because apart from the wings, which were designed to flap, lots of things flapped on the machine which should not have done so. But he knew that the author had designed and built a flapping wing machine and he wondered whether Mr. Lippisch would be willing to say something about the results of the work he did in that connection with his flapping wing glider. It was perhaps unnecessary to say that normally all pilots did not like flapping wings and he might mention that in the case of one flight, which he started in a normal fixed wing machine, the wings started flapping so much that he had to complete the flight in a parachute!

The fact that Mr. Lippisch started his career in the gliding movement, made him think of a recent experience whilst instructing at the Oxford University and City Gliding Club. A glider had landed in a field and the owner of it was very annoyed about it. When Mr. Kronfeld had tried to smooth him down the owner had said, " What's the use of gliding anyway? " It is much easier to explain this at a lecture of Mr. Lippisch's than in a field. Through gliding thousands of people can get in the air and can be made air-minded, who by other methods could not be interested in flying. Gliding not only taught people to fly, but also to observe and to put their theories into practice; for this the author is the best example.

The CHAIRMAN: They had been specially fortunate in having the discussion opened by Prof. Hill and they were equally fortunate in having present Prof. Melvill Jones of Cambridge, who would be good enough to make a few remarks by way of closing the discussion. He would ask Prof. Melvill Jones to propose a vote of thanks to Mr. Lippisch, and, at the same time, wished to say that the Society was now getting on for its 73rd year and no year had passed by in which they had not had the privilege of collaborating with those interested in aeronautics in Germany and in other countries, and this year would certainly be marked by the fact that they had had the lecture by Mr. Lippisch.

Prof. MELVILL JONES, C.B.E., A.F.C. (*Fellow*): On the subject matter of the paper it was hard to say anything at short notice. Much of what they had seen was new to him and to most of those present; he could not add much to the technical discussion without time to think about it. There was, however, one small point. They had seen the flapping wing with rigid trailing edge and also the wing with the flexible trailing edge, and the difference was that the latter gave a much more systematic flow with the vortices more definitely marked. He would like to know if the author could say to what extent that change altered the actual forces. Were the variations of lift which occurred greater or less with the flexible trailing edge and was the drag appreciably reduced by the cleaning up of the stream lines?

Prof. Melvill Jones said he must join with everybody else in congratulating the author on a very definite advance in technique in a type of experiment which was of great importance, and which had been rather neglected in the past. He agreed with the author on the value of being able to see the details of complicated phenomena of this kind before setting out to do mathematics about them. Flow phenomena were so complicated that nobody could represent them exactly in mathematics and, therefore, it was most important, before making necessary approximations, to get some clue by direct observation as to what approximations were likely to be legitimate and what were not.

In congratulating the author, Prof. Melvill Jones said the gesture towards international co-operation which the author had made in giving this lecture was much appreciated on this side. The difficulties of international co-operation related both to distance and language and it required a considerable effort to overcome the two. Anybody who made a serious effort to bridge the gap between nations in scientific matters was not only helping science but was helping the whole world towards a better understanding which might, in the end, bring about a closer relationship between people which would help to prevent wars. Scientists were often accused of inventing and producing things which were making war more horrible, and it was perfectly true that they had done so, though it was not their fault that the use made of their discoveries was often bad. Against that involuntary negative side of the scientists' work, could be set the fact that it was they more than anybody else who were trying to get together and co-operate; to get their ideas across to each other instead of keeping them secret for their own benefit. Anyone who took part in this aspect of scientific work was doing one of the most valuable things in the world at the present time. He would like to thank the author on every ground for the interesting and delightful lecture he had given.

The vote of thanks to the author was given with hearty acclamation.

Mr. A. FAGE (*Fellow*) (*contributed*): He had seen one of Mr. Lippisch's smoke tunnels in operation at the Air Cadets Academy, Gatow, near Berlin, and he had then formed the opinion, which had been strengthened by the films seen at the lecture, that the tunnel is an extremely valuable apparatus for demonstrating air flow. The films shown were not only helpful to the expert, but possessed a general educational value which, if they were shown at a cinema, would encourage air-mindedness in the general public. He would suggest that the extremely narrow cross section of the tunnel was not, in general, favourable to the observation of three-dimensional flow, and he would like to ask Mr. Lippisch whether he thought there would be any sacrifice of steadiness, if the same principles were used in the design of a tunnel having a much wider cross-section, and whether a change in technique would be necessary. He would also appreciate information on the shape of the jet nozzles, and also on the method of minimising the disturbing influences on the steadiness of flow arising from the presence of the long smoke tubes.

REPLY TO THE DISCUSSION BY MR. A. LIPPISCH (*Communicated*).

Before going into the different questions in detail, he would like to express his sincere thanks for the lively interest offered to the demonstration of the film. The high development of aeronautical science in Great Britain makes it difficult to anyone coming from outside to deliver something new and valuable. If he succeeded in doing so in a very limited degree, this was not due to the mere idea of the smoke tunnel but equally to the willing collaboration of all those who shunned no work and trouble whatsoever in helping him to realise this idea. His hearty thanks are due to them all.

The questions asked during the discussion referred to three main points and will therefore be treated jointly. There are first the questions in connection with the smoke tunnel itself which were mentioned by Prof. Hill, Dr. Townend, and Mr. Fage. The wind velocities inside the test field of the present realization of the smoke tunnel are up to 75 ft./sec. (24 m/s.). The section chord of the models was $15\frac{3}{4}$in. (40 cm.) in the normal tests and for special experiments which did not require high angles of attack or high lift wing sections up to a chord of 24in. (60 cm.) were employed. At the maximum velocity of 75 ft./sec. the smoke filaments are still distinctly visible. Therefore a Reynolds number of about 0.7×10^6 may be reached with the flow picture remaining clear.

The film shown was obtained at a wind velocity from 16.5 ft./sec. to 32 ft./sec.—corresponding to a Reynolds number of about 200,000—as the frequency of the slow motion camera of 1,000/sec. was not high enough for demonstrating the phenomena at a higher velocity. Though the camera is capable of giving a frequency of 3,000/sec., pictures could not be taken as the illumination of the test section could not be made strong enough.

It must be borne in mind that the pictures shown are the first of their kind and that the further development of the film technique for this purpose will allow the demonstration of flow configurations at much higher Reynolds numbers. The essentially new idea contained in the design of the smoke tunnel consists in the introduction of the smoke inside the entrance cone before reaching the proper test section. If the tapering of the cone is large enough it will always be possible to find a point where the smoke filaments enter the test room without dissolving. For special experiments, filaments up to a length of 10ft. were successfully obtained.

For obtaining perfect smoke filaments it is of decisive importance to make the jet highly free from turbulence. Instead of the normal honeycombs, he therefore employed fine nets which make the stream microturbulent. Besides, the tapering of the entrance cone must be greater than in normal wind tunnels. The taper ratio at present used is 12:1. In an improved tunnel, however, a ratio of 20:1

will be employed in order to obtain clear smoke filaments up to higher wind velocities. The distance between the glass walls of the test section amounts to $2\frac{3}{4}$in. and at first it was also feared that the boundary layer along the glass walls might have an unfavourable influence on the velocity distribution.

This fear was, however, unjustified. For one reason the surface of the glass walls is extremely smooth and for another the boundary layer seems to be turbulent from the very point of entrance of the test section, so that the velocity distribution is not markedly influenced by the boundary layer. When checking the velocity distribution in the back part of the tunnel a practically constant distribution was obtained.

It seems, however, favourable to increase the distance between the walls when designing an improved construction as it will then be possible to test a number of three-dimensional phenomena and to mount a device for force measurements. It must not be forgotten that the development of the smoke tunnel has not yet come to an end and that this first attempt is merely intended to indicate the direction along which further work can be done.

As regards the questions relating to the rotor wing, he would like to point out that they are here merely concerned with the demonstration of an aerodynamic phenomenon while the technical realisation of an aeroplane incorporating such a wing is an engineering problem.

In the combination of rotor and wing the acceleration of air through the slot gives thrust besides lift. As opposed to the method of sucking the boundary layer, the power used for driving the rotor therefore produces lift and thrust. In order to be able to land at the high lifts occurring at the great angles of incidence, it is therefore only necessary to be able to give the wing section behind the rotor a large angle of setting as referred to the fuselage axis. The technical realisation of such an adjustable wing is relatively simple, as the wing surface of a rotor wing may be greatly decreased as compared to the normal wing, owing to the greater lifts obtainable. In spite of all reverence towards tradition it must not be forgotten that after 100 years have passed men will no more fly by means of a birdlike flying apparatus, but with real " Flying machines."

In reply to the question put by Mr. Manning, regarding the yawing wing, the effect of flow deflection which can be observed in the film also takes place on the swept-back wing, though in this case it is not so marked. Different tests have shown that the sweep back causes a lift decrease towards the wing tips. On wings with marked sweep back the real position of the aerodynamic centre therefore lies farther forward than would result from the calculation based on the theory of the supporting vortex line, which does not take the influence of sweep back into account. The decrease of lift towards the wing tips of the swept-back wing as compared to the straight wing is confirmed by pressure distribution tests of the N.A.C.A.

To Mr. Kronfeld's question, the air waves may not be directly compared to the Kármán vortex street. If air waves are formed as in the case of the so-called " Moazagotl " in the Riesengebirge or in the Alps, air layers of different density must be present. The Föhn air waves may rather be compared to the water waves which are formed by the wind passing over the water surface. The density difference must be very great, so that the mixing process which leads to a damping of the waves cannot start at once.

The following deals with the different questions relating to the flapping wing:

The flapping wing which is mainly moving periodically up and down describes a flight path in the form of a wave as referred to the surrounding air.

As the direction of flow corresponds to the tangent drawn on the flight path curve of the wing, the air force produced by the wing is inclined forward when the wing moves downward, and backward when the wing moves upward (Fig. 7).

The down stroke with positive lift, therefore, causes thrust and the up stroke with positive lift causes drag.

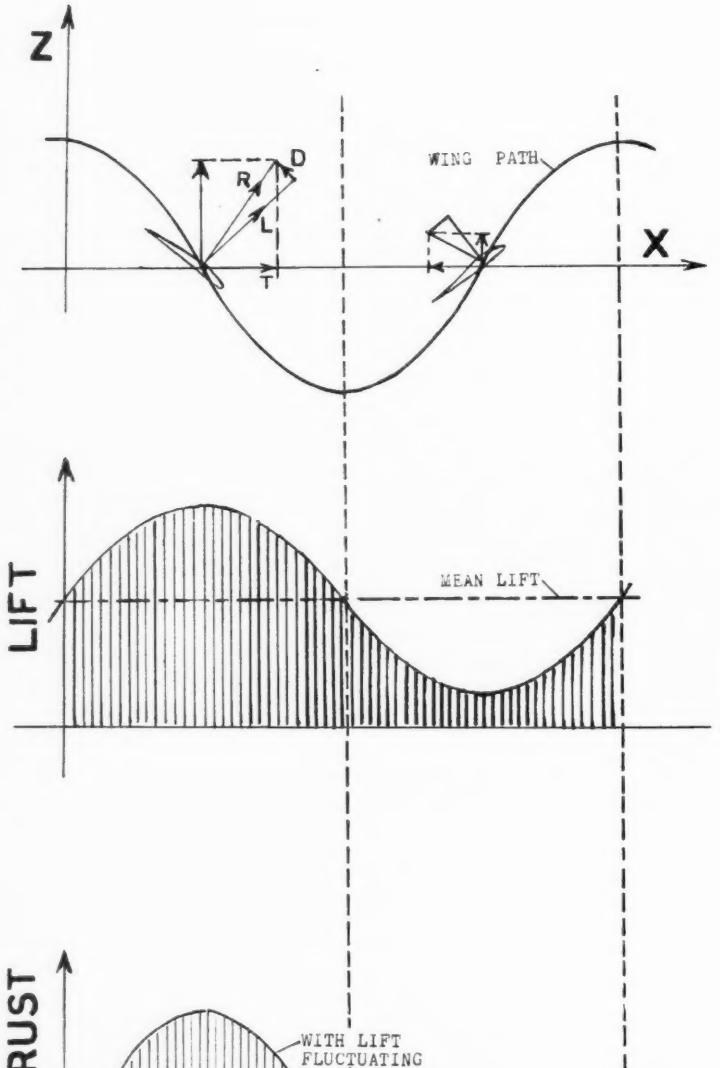

FIG. 7.

Flapping wing diagram.

In order to make the thrust obtained during the descent greater than the drag resulting from the ascent, lift must undergo a periodic change during every phase, reaching a high value during the downward movement and being small while the wing moves upward. If lift is kept constant during the whole oscillation the result will be a small drag instead of thrust.

The lift fluctuation on the other hand leads to the detachment of starting vortices and it is easy to understand that the obtainment of lift is dependent on the starting vortices being detached in time.

In the case of a rigid wing the starting vortex is only formed after a certain distance has been covered at the incidence in question. The phase of the lift fluctuation is therefore shifted against the periodic wing motion. It can be proved in a simple way that the thrust decrease is proportional to the cosine of the phase difference, while the thrust efficiency is decreased in an even higher degree.

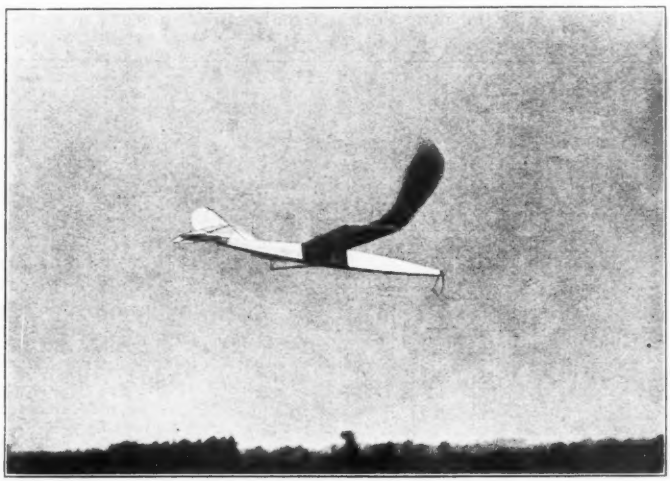

FIG. 8.

Flapping wing model "Lippisch," first design 1937.

The flexible trailing edge now leads to deflections of the wing section, and this additional motion of the trailing edge touches the starting vortices in the dead centre points. The starting vortex therefore does not arise from the motion of the wing as a whole, but from the superposed oscillation of the trailing edge.

They must keep in mind that flow about a flapping wing never becomes steady and that the obtainment of thrust by means of wing oscillations represents a classical example for the application of aerodynamics to periodic and constantly varying flow conditions. Research in this field of aerodynamic science has been very scarce up to the present day, and even the most elementary material required for deriving conclusions on the behaviour of a flapping wing is wanting.

The use of periodic and constantly varying flow conditions is—in the author's opinion—the real secret of bird's flight. It is highly probable that the power required for present-day aeroplanes in steady level flight is not comparable to the power required for operating a flapping wing. We must, therefore, make it quite clear that the question about the economy of flapping flight cannot yet be answered. The opinion that the bird requires much less power for flight than our airscrew-driven aeroplanes do, has already been defended by Lilienthal, and on the grounds of modern aerodynamic science this opinion can at least not be refuted.

The flexible trailing edge represents no fortuitous attribute of the bird's wing but a physical necessity for reaching good efficiency.

He applied this conclusion to the design of a number of flapping wing models which were driven by a pair of upward and downward striking wings instead of an airscrew. Good performance was obtained with these models.

On the first type of model the flapping wings were added to the tips of a rigid aerofoil (Fig. 8), while, in an improved design, the flapping wings serving exclusively for producing forward thrust were fitted to the fuselage nose (Fig. 9).

This is mentioned in order to show how the knowledge obtained from the smoke tunnel can be technically applied and that the flapping wing can be successfully employed in aircraft design.

In order to make the flow phenomena of the oscillating wing particularly clear, the film shows the periodic upward and downward motion at great changes of incidence and lift. The resulting starting vortex therefore is correspondingly vigorous. Consequently the wing does not make any " holes " in the air, but it

FIG. 9.

Flapping wing model " Lippisch," second design 1938.

detaches vigorous starting vortices which indicate that great lifts of periodically varying magnitude are being obtained.

All these phenomena offer a wide field for investigation, but within the scope of the lecture it was not possible to go more thoroughly into these most interesting problems.

The great interest which the demonstration of the film has met nevertheless shows that he succeeded in convincing the audience of the necessity of similar experiments by means of visible aerodynamics.

In conclusion he wanted to give the Royal Aeronautical Society his sincere thanks for the invitation to hold the lecture. In former times it was the custom for the guest to bring a gift from his home country. He begged that this first demonstration of a new method of flow investigation may be considered as a guest's present. Though we are working for the development of aeronautical science in different countries we will always strive for the general diffusion of human knowledge.

INVESTIGATIONS ON THE SAFETY OF THE TAKE-OFF OF AEROPLANES IN CONNECTION WITH THE QUALITIES OF THE AEROPLANE. 1938.*

(Commission for the Investigation of Aircraft Material. (C.K.L.) Appointed by the Minister of Waterstaat, in accordance with the Regulation of 31st December, 1936, No. La.K.K.).

Secretariat: Schiphol Aerodrome.
(Block C. Room 27.)

Report prepared on behalf of the Commission by Ing. A. G. VON BAUMHAUER (Member of the Commission) and P. DE WINTER (Sec.)

Amsterdam, 7th November, 1938.
Translated by M. FLINT.

GENERAL REMARKS.

Investigations have been carried out in connection with the testing of a definite aeroplane type in order to ascertain the extent to which the safe take-off can be sufficiently ensured by prescribing certain practical requirements.

This led to inquiries into the question as to whether the qualities of the aeroplane in the take-off could be determined from individual tests, in such a way that it would be possible, from the results, to determine the take-off path when climbing in conformity with a definite previously established policy.

The present report consists of an analytical consideration of the safety in the take-off, which may be used as a practical guide for the predetermination of a safe take-off policy, and a means whereby the dimensions of an aerodrome, such as shall meet the rational requirements for a safe take-off (of a definite aeroplane type), can be determined.

For the assessment of the " safe " take-off, a method of consideration has been adopted which is comparable with the detailed analysis applied in the assessment of the safety of a structural component in the strength specifications.

In order to obtain the data necessary to enable assessment to be made of the take-off qualities of an aeroplane, it should be noted that it has been the usual practice to correct an arbitrary take-off to normal conditions with regard to ground and atmosphere, but the arbitrary choice in the take-off policy adopted by the pilot has not been eliminated.

This led the commission to develop a method which is embodied in the so-called " C.K.L. diagram."

Besides the elimination of the above-mentioned arbitrary choice, this diagram can be used equally well for the determination of the take-off path when a prescribed climbing policy is followed.

This is done by a graphical method, also described in the present report, and by means of which the computations are rendered accessible to the draughtsman.

The mathematical explanation of the methods followed is given in the Appendix.

* Translated by R.T.P., Air Ministry, and published by courtesy of the Air Ministry.

RESULTS OF THE INVESTIGATIONS.

(*a*) It has been found possible to formulate requirements for the safe take-off and the dimensions of an aerodrome necessary in order to satisfy these requirements.

(*b*) The C.K.L. diagram presents the possibility of eliminating the personal factor of the pilot from the take-off data.

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Chapter I.

Introduction.

Experience has shown that many serious aeroplane accidents have occurred in the process of taking off.

The explanation lies in the fact that in the transition from the run on the ground to actual flight in the air, the aeroplane passes through the region of low flight speeds.

It is just in this transitional region from " not-flying to " flying," *i.e.*, the region of low speeds, that the safety of the flight is small owing to the risk of stalling and the still highly imperfect controllability.

In connection with the foregoing remark, the take-off is understood to be the progress from the position of rest on the ground to the state of flying.

In the following considerations the term " normal start " is understood to cover the whole of the progress from the position of rest on the ground to the state of " safe " flying under normal conditions, *i.e.*, in which a safe speed and a safe height have been attained.

In the region of low speeds the disturbing influence of a combination of secondary factors may become very serious, and for this reason this region of speeds may be called the " vulnerable region."

Of these disturbances, attention is drawn in particular to those in consequence of which the pilot, in the effort to overcome them, stalls.

The risks associated with the flight through the vulnerable region may be diminished by adopting a cautious take-off policy, namely by reducing as much as possible both the time taken in flying through this region and the height and hence also the possible consequences of a mishap.

These considerations lead to the assumption that with reasonable discretion on the part of the pilot the dangers entailed by these disturbing factors can be greatly reduced.

This conclusion is based on the fact that the safety of flight depends both on the flying material and on the personnel. It may moreover be said that the safety increases when gross errors in handling entail no danger, and conversely when large material defects may be overcome by proper discretion and good handling.

The present investigations on the safety of the take-off are concerned entirely with land planes such as are in general use in the Netherlands, the acceleration for the take-off being derived exclusively from the traction of the airscrews.

Devices such as catapults or other systems accelerating take-off are not taken into consideration. Attention may, however, be drawn to the fact that, with these auxiliary devices, there need be no " free " flight in the vulnerable region.

(*a*) Method of Consideration of the Safety of the Take-off Analogous to that of the Safety of a Structural Component.

For the consideration of the safety of the take-off, a method has been applied which is analogous to that employed for the definition of the safety of a loaded component of an aeroplane, according to the Netherlands Regulations for the Inspection of Aircraft.

Normal stress is defined as the material stress which is produced under normal load.

With the possible over-loads, namely the loads considered as probable, the possible stress is produced. This latter stress is accordingly defined as equal to: normal stress multiplied by the excess load factor.

In combination with the various causes which cannot be determined accurately beforehand, higher stresses may be produced. In order to ensure safety, additional stresses are allowed for the probability of the occurrence of which is extremely small. These calculated stresses are obtained by multiplying the possible stresses by the factor of safety $(=2)$.

These calculated stresses must be smaller than the permissible stresses resulting from the material qualities for the manner of loading. If the permissible stress is greater than the calculated stress the term " excess safety " is applied.

Among the factors which hamper the take-off, viz., which increase its length, there are some which frequently occur and hence are considered as " probable." Their effect may, by analogy, be called the " possible lengthening " of the normal take-off. (The expression " possible hindrance of the take-off " is less suitable here.)

The possible length is thus found by multiplying the normal length of the take-off by the " factor of possible lengthening."

In view of less frequent unfavourable influences, it is necessary to introduce a factor of safety, which, multiplied by the possible take-off length, gives the calculated take-off length (or *calculated length*).

This calculated length must be smaller than the permissible length in relation to the dimensions of the aerodrome (for a definite take-off direction).

If the permissible take-off length is greater than the calculated length, we have an excess of safety.

It is then seen that the method of consideration of the safety of a structural part can be consistently applied to the safety of the take-off.

(*b*) Existing Requirements.

These requirements relate on the one hand to the climbing capacity of the aeroplane immediately after leaving the ground, and on the other, to the safety of the flight at low speeds, these latter characteristics as already mentioned having an important influence on the safety of the take-off.

The requirements relative to the climb of aeroplanes are specified in Art. 120 of the R.T.L. (Netherlands Air Regulations) and Art. 4, paragraph 1 of the Regulations of the Ministry of Waterstaat, of the 30th January, 1936. No. 471 II. Briefly they are as follows:—

1. To reach a height of 20 metres at a distance of 600 metres from the starting point (*i.e.*, the place where the aeroplane begins to move).
2. The flight path, after reaching the height of 20 metres, must have a mean gradient of not less than 7 per cent.
3. A height of not less than 220 metres must be reached within three minutes.

The requirement specified in para. 1 above is a minimum requirement which is imposed on the material. Since no limits are specified here for the lowest speed at which this 20-metre obstruction must be cleared, this requirement cannot be regarded as a safety requirement, though it may be as a performance requirement.

This requirement appears already in the earliest British regulations, and has been adopted in many countries through the I.C.A.N.

The requirement in paragraph two specifies that the aeroplane, also, after clearing the obstruction, should be able to continue to climb following a path with a definite inclination, specified as a minimum.

In paragraph three a requirement is specified concerning the absolute climbing speed.

This is based on the assumption that the climbing capacity is maintained with downward velocities regarded as possible in disturbed air. No good grounds for this, however, are given.

For the take-off in mountainous country, however, there may perhaps be every reason for a requirement of this kind.

The requirements in paragraphs two and three are derived from the I.C.A.N. Regulations.

With regard to the safety in flight, the requirements are laid down in section III of the Netherlands Regulations (471 II), the general Art. 6. of which runs as follows:—

" In all conditions of flight aeroplanes must be stable about the three principal axes and be easily controllable."

The term " all conditions of flight," here, also, includes the flight immediately after leaving the ground.

For aeroplanes of category I (limited to normal flying) the requirements concerning stability and controllability when " flying at large angles of incidence " are specified in detail in Art. II, paragraphs (*a*) and (*b*) of the above regulations, viz:—

II. Commercial aeroplanes and aeroplanes of category I which are not commercial aeroplanes, must, in addition to the foregoing requirements, satisfy the following requirements.

" *Controllability.*

At a speed of approximately 10 per cent. below the speed at which the rate of climb is greatest, the machine must be capable of being flown in a straight line with one engine shut off without excessive exertion. In this condition of flight the machine must be completely manœuvrable with the rudders for flying in disturbed air. Use may be made of devices for reducing the forces on the controls, such as trimming flaps, etc.

The deflection of the control surface, which, calculated from the central position, is necessary in order to fly straight in this condition of flight, must not be more than 80 per cent. of the available lateral deflection of the rudder out of the central position.

When, with engine(s) shut off, the angle of incidence of the wing is slowly increased by moving the control column (or control wheel) right back till it reaches or exceeds the angle corresponding to the minimum flying speed (critical angle of incidence), the aeroplane except in the case referred to hereafter, must remain in flight in the position obtained or automatically and gradually pass into normal flight with an angle of incidence smaller than that referred to above.

If, in the case of commercial aeroplanes with a maximum permissible total loaded weight of more than 5,000kg., the flying qualities are such that, with the increase of the angle of incidence, the pilot, after moving back the control column or the control wheel to a considerable distance, on a further movement in this direction definitely notices (*e.g.*, by the fact that the force on the controls, the angle of attitude of the aeroplane or the angle of the elevator, necessary to impart to the aeroplane a safe change of incidence, increases to a marked extent, or by the fact that the aeroplane performs characteristic, not dangerous, but warning movements or if the pilot is warned by some suitable instrument or some other effective manner) that the angle of incidence is approaching the critical value and that the occurrence of an uncontrollable movement is highly possible, the requirement specified in the foregoing paragraph need not be fulfilled and the flying qualities at larger angles of incidence need not be tested.

In no case in the tests carried out for the above purpose must any excessive lateral or sudden movement of the aeroplane take place, the ailerons and the rudder must always remain fully effective."

The requirements laid down in the above specifications deal with the safety in soaring flight (without engines). As already explained in the introduction to the present chapter, the safety of the take-off when the aeroplane passes through the region of low speeds is small owing, amongst other things, to the risk of stalling.

This stalling is, however, intended for powered flight, so that when considering the safety in the take-off the stalling limits with engines running should also be indicated under the different circumstances as specified in this article.

The stalling speeds with engines running are lower than in flight without engines as may be assumed as known.

If now the stalling limits with and without engines lie far apart and if the behaviour of the aeroplane at large angles of incidence with engines running is not in conformity with that specified for flight without engines, the sudden shutting off of an engine may then render the condition of flight dangerous, since the aeroplane, at the moment the interruption occurs, has a speed which lies between the intended limits. The result of the shutting off of the engine then is that the aeroplane performs uncontrolled movements without action on the part of the pilot.

That safety in flight must be maintained in the event of engine trouble is seen from Art. 8, paragraphs two and three, which run as follows:—

2. If, in the case of powered flight, one or more engines should suddenly fail, the movement of the aeroplane caused thereby must be capable of being easily counteracted by moderate operations of the controls.

3. In the case of multi-engined aeroplanes, if in rectilinear flight with engines running at speeds between the minimum and the maximum speeds, one engine is suddenly stopped, any possible rotation of the aeroplane caused by this stopping of the engine must be capable of being counteracted by moderate operations of the controls.

(*c*) Dangers Associated with the Take-off.

This next section deals with the dangers associated with the take-off, where, without going into the details of the various accidents themselves, use is made of the experience hitherto obtained with Dutch and foreign aeroplanes.

These dangers may be classified under different headings, viz: according to the manner in which the aeroplane departs from the normal take-off; according to the possibility of safeguarding against dangerous conditions, and finally, according to the result.

Classification of the Dangers Associated with Taking-off According to Effect.

1. Type of effect.
   (*a*) Collision with obstruction.
   (*b*) Uncontrolled motion: Stalling, nose diving, swinging round and dropping a wing.
   (*c*) Contact with the ground: Nose diving into the ground, slewing along the ground.
2. Possibility of safeguarding.
   (*a*) Ease in flattening out (low height necessary).
   (*b*) Not to recover (large altitude required).
3. Result.
   (*a*) Small damage.
   (*b*) Destruction of the aeroplane.

In order to be able to increase safety, it is desirable to know the sources of danger. These sources which are the possible causes of accidents may be classed according to (*a*) the seriousness of the results; (*b*) the frequency of their occurrence; (*c*) the moment during the take-off when they occur; (*d*) their origins and knowledge about them.

Classification of Sources of Danger According to Type.

1. Seriousness.
   (*a*) Small danger.
   (*b*) Dangerous.

2. Frequency.
   (*a*) Rare (by chance).
   (*b*) Frequent (probable).
3. Moment of occurrence.
   (*a*) At the beginning of the take-off or at greater altitude.
   (*b*) In the vulnerable region.
4. Origin.
   (*a*) Atmospheric conditions.
   (*b*) State of the ground.
   (*c*) Material.
   (*d*) Personal.
5. Knowledge about the source of danger.
   (*a*) Unknown definitely.
   (*b*) Approximately known.

The seriousness of a source of danger depends on the frequency with which it appears and on its consequences.

The frequency can be assessed from experience both as the whole cause and as a partial cause of mishap when taking off.

The moment the cause of the danger arises in many cases is decisive, because it depends on this whether the pilot, by seizing the situation, is able to avert the danger, either by discontinuing the take-off or by restoring the aeroplane to normal flight.

Whether the take-off can be discontinued depends on having a completely unobstructed ground on which the aeroplane can be immediately relanded.

With regard to the origin of the danger it may be mentioned that unfavourable atmospheric and ground conditions generally tend to increase the length of the take-off by reducing the acceleration power and hence the acceleration in the take-off.

The influence of abnormal atmospheric conditions may be predicted by applying the method described in the present report.

The influence of large ground friction, slope of the surface, and height of the aerodrome above sea-level may also be taken into account, provided the state of the aerodrome is known beforehand (of chaps. 2(*b*), 2 and 3).

Defects in the material may reduce the acceleration besides causing the aeroplane, by reason of the flying qualities, to be brought suddenly into a dangerous flying position.

Errors on the part of the personnel may occur at any stage of the taking-off. They may result in many kinds of trouble.

Knowledge of the sources of danger obviously is of great importance since such knowledge renders it possible to judge whether the dangers can in general be overcome and also enables the crew, in the case of a definite take-off, to weigh them up and take any necessary special precautionary measures.

The dangers of more frequent occurrence are described in the section (*d*) with particulars as to the possible difficulties entailed in the take-off, whilst the less frequent dangers are referred to in section (*e*) which also deals with the determination of the factor of safety.

(*d*) Determination of the "Possible Hampering of the Take-off."

The various factors which most frequently occur and hamper the take-off are primarily those associated with the atmospheric and ground conditions. Others which may occur relatively frequently are one or other of the many possible technical troubles in connection with the flying material or errors in pilotage.

As for the assessment of the excess loads on structural parts occurring under normal service conditions, an estimate must be made of the hampering of the take-off to be regarded as reasonable in normal service.

The influence of each of the above causes may be given more or less approximately.

The frequency with which the causes occur, however, cannot be specified, because the necessary statistical data are not at present available. It cannot be said, for example, whether a high temperature or a low barometric pressure will occur once in 100 or 1,000 take-offs; it depends on the region in which the aeroplane is used (*e.g.*, Europe, the Tropics, etc.), and also on the height of the aerodrome above sea-level. With regard to the simultaneous occurrence of all or none of the various unfavourable factors, it is again impossible to form any approximate estimate. It seems highly probable that the chance of errors of pilotage increases as the material and atmospheric conditions become less favourable.

The choice as to which disturbances should be considered normal and which as abnormal is arbitrary. In their assessment it is assumed here that the simultaneous occurrence of three not-abnormally great disturbing influences in normal service may be considered as a probable, and hence as a possible, hampering of the take-off. In the cases where all the hampering factors are unknown beforehand, a larger number of disturbing influences or a more severe hampering of the take-off would have to be assumed. Thus, if it is known, before taking off, that the atmospheric and surface conditions are highly unfavourable, the take-off should be abandoned unless the dimensions of the aerodrome and the freedom of the surroundings from obstructions render it still possible to take off safely with a greatly lengthened path.

The following considerations, in which numerical values are given for the possible lengthening of the take-off, are based on the available data for the take-off of a modern commercial aeroplane (land-plane). This aeroplane is fitted with engines with adjustable airscrews and superchargers, by means of which the output during the take-off is much greater than the normal. This aeroplane then also acquires an acceleration force which is greater than that of many other aeroplanes which derive their take-off acceleration solely from the airscrew. The acceleration force measured at the beginning of the take-off is approximately 30 per cent. of the weight of the aeroplane. The calculation of the values referred to is given in the Appendix by application of the C.K.L. diagram.

For aeroplanes with relatively smaller acceleration force the same disturbing factors cause greater lengthening of the take-off.

The various factors hampering the take-off assumed here as "possible," are given in the following table:

No.	Origin.	Condition.	Increase in length of take-off.	Factor.
1.	Atmosphere.	Air temperature 44°C.	18%	1.18
2.	Atmosphere	Height of barometer 722 mm. ...	13%	1.13
3.	Ground	Friction co-efficient 0.10	12%	1.12
4.	Material	Various	10%	1.10
5.	Personnel	Various	10%	1.10

As a result of the simultaneous occurrence of three of these hampering factors a maximum value of 49 per cent. is found for the increase in length of the take-off. The product of the factors derived from the three largest influences is namely:

$$1.18 \times 1.13 \times 1.12 = 1.49.$$

For the aeroplane type concerned the "possible length of take-off" is thus equal to 1.5 times the normal. The "possible lengthening factor" is 1.50.

The following considerations may serve to explain the assumed values:

1. An increase in the air temperature of 10 per cent. above the normal value of 15° or 288° absolute, hence to 44°C., never occurs in the Netherlands, though it certainly does in the tropics. The consequent lengthening of the take-off in the case of the aeroplane under consideration is established as 18 per cent. (factor 1.18) (cf. chapter 2(*b*) 6).

2. A drop of 5 per cent. in the atmospheric pressure occurs quite frequently in Europe, hence the height of the barometer is 722 mm. instead of 760 mm. It is found by calculation that the length of the take-off for the same aeroplane is thereby increased by 13 per cent. (factor 1.13) (cf. chapter 2(*b*) 6).

The height of an aerodrome above sea-level has the same influence as a reduction of the air pressure or an increase in the air temperature (cf. case 2 and 1). Hence this influence is not dealt with separately here.

3. On a good runway or a hard turf with short grass the friction co-efficient is 0.05, an increase of 0.05 will therefore produce an increase in the length of the take-off of 12 per cent. (factor 1.12) (cf. chapter 2(*b*) 3), where the length of run is taken as far as the " unsticking " speed (40 m/sec.) corresponding to that of the aeroplane concerned.

It must be borne in mind that, under unfavourable conditions, the friction coefficient of an aeroplane running over the ground may be considerably larger than the value 0.10 assumed here; this is the case, for example, when a surface has a high overgrowth (long grass) or is muddy.

This may even render a take-off impossible, particularly in the case of an aeroplane with a small margin of output (small acceleration power).

Conditions of this kind, however, cannot be regarded as normal for commercial air traffic.

Should such abnormal ground conditions occur, the take-off should be abandoned or suitable measures be taken to safeguard the take-off: such a measure would be a considerable reduction of the weight of the aeroplane.

4. For the " possible " technical troubles a moderate disturbance is assumed such as: the starting of a wheel brake, inadequate ignition in the engine, a defect in the airscrew adjustment system, a fault in one of the important instruments and the like.

The assumption that these troubles produce an increase of 10 per cent. in the length of the take-off (factor 1.10) is entirely arbitrary.

5. For the " possible " errors in handling the aeroplane the following are taken into consideration: errors in pilotage, such as not taking off directly into the wind, flying at an unfavourably large angle of incidence, allowing the machine to run out of the course (too much yaw), etc.: incorrect lading of the aeroplane, slight overloading due to an error in the estimate of the load carried, etc.

The probability of errors in pilotage is greater in " blind take-offs." Small deviations in the path of the aeroplane under these circumstances may be found to lead to more trouble than in the case of take-offs with good visibility.

Here again the assumption of an increase in the length of the take-off of 10 per cent. is entirely arbitrary.

(*c*) Establishment of the Factor of Safety.

For the estimation of the value of this factor it is necessary primarily to know the dangers of rare occurrence, the influence of which exceeds those of the possible " hampering " factors.

Some results may even be so serious that the take-off has to be discontinued, for example: " a ground loop," sudden blocking of the wheel brakes, cutting out of an engine during or very shortly after the starting run. Some of the less frequent dangers are referred to below, the various conditions as given in the Table and dealt with under paragraph 1(*d*) above the present chapter being again considered.

Dangers Due to Atmospheric Conditions.

Taking off with ice accretion on the wings: taking off with veering wind, sudden bad visibility; disturbed air (turbulence, caused in connection with obstructions on the aerodrome).

Particular conditions of the aerodrome such as local sogginess or unevenness.

Certain material dangers such as: the sudden stopping of an engine after the take-off run before the safe speed has been attained; " shimmy " of the tail or nose wheel; " ground loop " (uncontrolled swing).

Finally. Operational Errors on the Part of the Crew.

In the second place the obstructions on or in the neighbourhood of the aerodrome must be taken into consideration.

The obstructions on the aerodrome rarely constitute a solid obstruction front, as, for example, woods, because to-day it is possible almost universally to count on finding safe gliding-in tracks of sufficient width, thereby affording a safeguard for the take-off.

On certain of the aerodromes in service in the Netherlands there are isolated high buildings. Obviously a cautious pilot will avoid taking off heading towards obstructions of this kind, but in the case of bad visibility their presence nevertheless will certainly render use of the aerodrome unsafe. This applies equally to high obstructions such as high buildings or natural obstructions in the vicinity bordering on the aerodrome. As a result of the earlier investigations on the danger of obstructions, in the course of time amendments have been repeatedly made in air traffic laws. The substance of Art. 28, which specifies the heights of obstructions situated up to a distance of 5,000 metres from the boundary of an aerodrome is as follows:—

" Prohibition of obstructive works and operations on and above adjacent areas.

1. It is prohibited, in so far as a prohibition extending to the land areas (parcels) concerned comes under the jurisdiction of the (Netherlands) Minister:—

(*a*) On or above parcels or parts of parcels of land situated at or less than a distance of 400 metres from the boundaries of an aerodrome:—

1. To erect or to plant, or to have either buildings or plants or wood growths.

2. To erect or to have either buildings or plants or wood growths exceeding a height to be specified.

(*b*) On or above parcels or parts of parcels situated at a distance of more than 400 metres but less than 700 metres: To erect or to have buildings of plants or wood growths of more than a specified height of 10 metres or more.

(*c*) On or above parcels or parts of parcels situated at a distance of more than 700 metres but less than 1,000 metres: To erect or to have buildings or plants or wood growths of more than a specified height of 20 metres or more.

(*d*) On or above parcels or parts of parcels situated at a distance of more than 1,000 metres but less than 5,000 metres: To erect or to have buildings or plants or wood growths of more than a specified height of 25 metres or more.

2. A prohibition as defined in paragraph 1 does not apply to:—

(*a*) Buildings existing at the time of the publication in the Staatscourant specified in Art. 31, para. 2.

(*b*) Buildings or structures begun and still in course of erection in accordance with a previously established plan, prior to the publication.

(*c*) Reconstructions and rebuilding works, in so far as the reconstruction or new building does not differ to any important extent from the original construction."

Before considering the value of the factor of safety it is necessary, in connection with the possible presence of obstructions, to determine at what height the normal take-off (*cf.* Introduction to the present chapter) is calculated to end. It must at the same time be borne in mind that this height must offer the pilot sufficient

manœuvring space, for example, in the case where one engine (*e.g.*, in a twin-engined aeroplane) stops during the take-off, to allow him to continue flight for the purpose of landing on the same aerodrome.

In the present considerations a height of 10 metres is regarded as reasonable, on the assumption that a very high local obstruction can be avoided.

For the factor of safety a value of 1.20 is suggested.

From the list of sources of disturbance given in section (*d*) of the present chapter, it may be seen that there are many sources of disturbance, though these may perhaps be less probable, which may justify the necessity of a higher factor of safety. Many of these factors, however, may be known beforehand, so that it is possible to safeguard against them, either by following a very cautious take-off policy or by abandoning the start.

A more definite estimate of the factor of safety could also be given if more statistical material concerning the various disturbances were available.

The product of the possible path lengthening factor and the factor of safety is then $1.50 \times 1.20 = 1.8$, namely: the " calculated length of the take-off " is equal to 1.8 times the " normal length of take-off " of the aeroplane type concerned.

If the take-off length should exceed the calculated length an accident must be regarded as a certainty in cases where the excess of safety of the aerodrome is zero.

Chapter II.

Investigations on the Take-off.

(*a*) The C.K.L. Diagram.

1. General Considerations, Influence of the Path Gradient.

Chapter 1, section (*b*), contains a review of the Netherlands Regulations for Airworthiness. A necessary addition to these requirements is that they must be satisfied under so-called " standard " or normal conditions of the air and of the ground.

Normal Conditions.

The condition of the air is defined as normal when the pressure is equal to 760 mm. Hg., the temperature 15°C. and the wind velocity, measured at three metres above the ground, is 2.5 m/s.

The normal condition of an aerodrome is not described in detail in these regulations, although it has already been long known that the ground friction factors differ very widely for a grass surface, in dry or wet condition, with short or high growth, or a hard ground surface.

In the following considerations a value of 0.05 is assumed as normal for the ground friction factor (*mu*), this being roughly applicable to the conditions obtained at air ports which are to-day generally provided with concrete or asphalt runways.

For aerodromes which do not lie at sea-level, but at moderate heights, and, thus, where the air is on an average more rarefied than the normal atmosphere as described above, the hampering of the take-off, thereby entailed, provided this lies within given limits (chapter I(*d*)), may be considered as equivalent to one which is equally liable to occur as a result of other possible conditions in normal service.

In tests carried out to determine the extent to which an aeroplane satisfies the above requirements, the data obtained, such as the take-off length, the height attained and the time, must therefore be corrected to appropriate normal conditions.

METHODS OF CORRECTION.

These methods of correction must satisfy the requirement that, when applied to the data measured in the tests under conditions differing from the normal, they shall always give the same values for the take-off length, the height attained and time.

The existing methods of calculation, in which, *inter alia*, the influence of larger ground friction or rarefied air is assumed, do not satisfy this requirement, because in these usual methods of correction the arbitrary take-off policy adopted by the pilot, in other words, the personal element, is not excluded.

Correction methods for the purpose in view must thus be supplemented by one which renders it possible to " eliminate the arbitrary take-off policy."

The total propulsive power which is at the disposal of the pilot for the purpose of starting the aeroplane and getting it into the air, viz., the " free acceleration power " is equal to the thrust of the airscrew(s) reduced by the drag of the aeroplane.

This acceleration power in the air depends on the flight speed alone, since both the airscrew thrust and the drag depend only on the speed. For the present no account will be taken of small secondary disturbing influences. These will be considered in detail elsewhere in this report. The acceleration power enables the pilot to adjust the flight path arbitrarily within certain limits. He can employ part of it, for instance, to climb, but then only a smaller amount of power will still remain over to allow him to increase the speed of the aeroplane. Climbing, in fact, gives rise to an opposing force which reduces the disposable acceleration power by a value which is proportional to the slope of the path, *e.g.*, with a path gradient of 1/10 the available acceleration force is reduced by 1/10 of the weight of the aeroplane. This reduction in the weight which depends on flight path may be called the " path force."

If, on the contrary, at a certain point of the flight path, the path force is added to the acceleration force, the total acceleration force disposable at the corresponding flight speed will be found.

If this is done for paths of differing gradient the same total acceleration force will be found with any speed.

In this way data are obtained from one take-off, from which the possibilities of a take-off can be determined, in which the path gradient selected by the pilot and hence the personal element is " eliminated."

The measurement of the thrust of the airscrew(s) and the drag of the aeroplane during the take-off, namely, the starting run and in flight, at the moment presents considerable difficulties, so that measurement is made instead of the longitudinal acceleration of the aeroplane at different speeds. It may then be noted that, with an acceleration force of 30 per cent. of the weight of the aeroplane, the longitudinal acceleration of the aeroplane is 30 per cent. of the acceleration due to gravity (approximately 3 m./sec.^{2}).

During the climb the disposable longitudinal acceleration is reduced by the gravitational acceleration in the direction of the path.

In the C.K.L. diagram the relation is given between the disposable longitudinal acceleration (total acceleration) and the corresponding speed.

The acceleration given in this diagram is thus the acceleration the aeroplane should have when passing through the various speeds, if the aeroplane is kept low throughout the take-off (*i.e.*, with path gradient zero).

The accompanying Fig. 1 shows the relation between acceleration and speed. The values are those measured with the modern commercial transport aeroplane referred to in chapter I(*d*).

These are $a = 3$ m./sec.^{2} at the beginning ($v = o$) and $a = 1.6$ m./sec.^{2} at $v = 50$ m./sec. or 180 km./hr. It is further assumed that the aeroplane " unsticks " at $v = 40$ m./sec. (144 km./hr.). As the lengths of path and heights

are expressed in metres and the acceleration is also given in m./sec.^{2}, the speed, to be consistent, is also given in m./sec.

Curve I in Fig. 1 gives the total acceleration, and Curve II the remaining longitudinal acceleration which continues to be available during the climb in order to accelerate the aeroplane in the longitudinal direction. The selected path gradient of Curve II is 10 per cent.

From the relation between acceleration and speed, it is possible to determine the appropriate flight paths with the corresponding heights.

In this general consideration it is noted that the drag of the aeroplane is dependent only on the speed.

This, however, only holds precisely when the angle of incidence is either constant or when it varies in a definite manner with the speed.

In the first part of the take-off run the angle of incidence is constant when the wheels fore and aft are in contact with the ground.

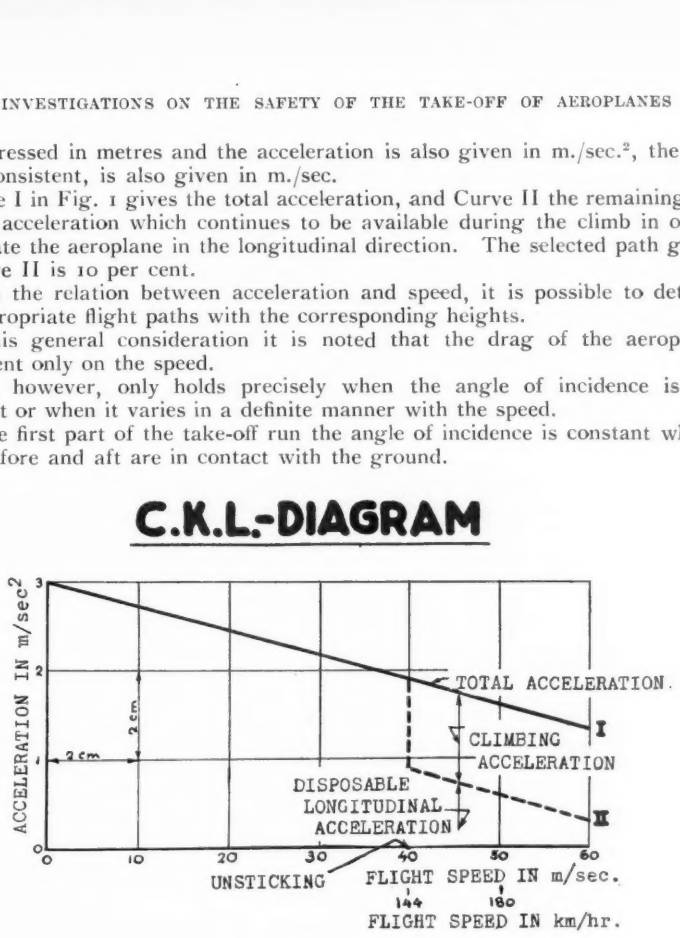


FIG. 1.

Simple C.K.L. diagram with two example curves.

When the aeroplane ceases to be in contact with the ground, there is a definite drag (air resistance) corresponding to a sequence of conditions of equilibrium (trim) for every speed or dynamic pressure. In the transition region in which the pilot can vary the position of the aeroplane, the above assertion holds only roughly. Since in this region the airscrew thrust is much greater than the air resistance, a small variation in the resistance will have little influence. Besides this a reduction of the angle of incidence, and, hence, a reduction of the resistance owing to a reduction of the lifting force of the wings, occurs in conjunction with an increase in the wheel friction, which variations in the main cancel each other out.

2. DETERMINATION OF THE C.K.L. DIAGRAM.

For the determination of the take-off data it is necessary to determine the longitudinal acceleration of the aeroplane and the gradient of the path at a series of points during the take-off.

In order to increase the approximation it is useful to reduce as far as possible the influence of the path gradient, of the climb and of the height. This can be achieved by flying level so that the path gradient remains zero whilst the height is maintained constant.

The measurement of the path gradient may then be omitted, the influence of the increase of the wind speed, moreover, is immaterial. The influence of the ground on the air resistance which, in itself, is small, with this flight at constant height, may be approximately determined by calculation and may thus be omitted.

The longitudinal acceleration and also the path gradient have been determined in a series of take-off measurements on the commercial aeroplane referred to above, with the aid of the " take-off cine (camera) " of the Dutch National Aeronautical Laboratory. This gives, in the first place, the connection between length of path, height and time. From this, by differentiation twice of the distance with respect to the time, the longitudinal acceleration can be deduced. From the rate of climb and the horizontal speed, taking into account the wind velocity, the path gradient of the aeroplane is determined. Different take-offs were recorded for these measurements, in some of which the aeroplane was made to climb and others not.

A more direct method of measurement in a provisional form has been tested by the C.K.L., in which the longitudinal acceleration is found from the slope made by a fluid level in the longitudinal plane of the aeroplane with the horizon. As a result of the longitudinal acceleration the fluid remains aft, *i.e.*, in the after branch of a U-tube fixed in the aeroplane, the fluid rises higher than in the forward branch.

The position of the fluid in the U-tube, suspended in front of a frame, with respect to the horizon, is established with the aid of a small cine-camera. The course of the longitudinal acceleration found in this manner is in good agreement with the measurements referred to above.

It is useful at the same time to photograph the indications of a speed indicator, a second-clock and one or two engine instruments.

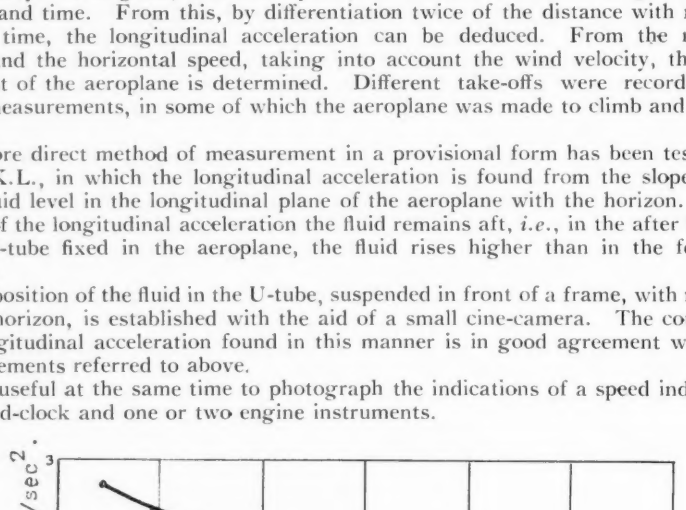


FIG 2.

A C.K.L. diagram for a modern transport aeroplane obtained by means of the cine-method.

Fig. 2 is an example of a C.K.L. diagram obtained by the cine-method. It is seen that here a curve is obtained which is approximately straight, but yet displays a definite " wave." In particular at the beginning of the climb a trough appears, followed shortly afterwards by a crest. It is seen from the simultaneously photographed elevator control that there is a corresponding preliminary " pull " and " push " on this control.

This trough in the acceleration curve indicates a temporary increase in the air resistance of the aeroplane, which must be the result of: the increase of the lifting force necessary to accelerate the aeroplane for the upward climb; and the increase of the wing resistance with the rapid increase of the angle of incidence.

In order to avoid this increase in resistance so as to render a short take-off possible, it is desirable for the aeroplane to be manœuvred as gradually as possible. For these reasons also it is advisable when carrying out the tests for the C.K.L. diagram not to make the aeroplane climb, but to keep low over the ground (*cf.* Chapter 2 (*a*) 1).

For the sake of completeness a third method may be mentioned by means of which a considerable part of the C.K.L. diagram can be determined experimentally. In this case the gradient is determined in the climbing position in a series of speeds in steady flight (longitudinal acceleration zero, maximum gradient).

This method is thus the opposite of those described above, since there the acceleration is maximum and the gradient of the path is zero.

The disposable acceleration is found by multiplying the path gradient found, by the acceleration due to gravity.

The drawback of this third method is that it teaches nothing concerning the first part of the take-off, *i.e.*, the starting run, in which the speed is less than the minimum flying speed. This part can, however, be easily investigated when the attitude of the aeroplane remains unchanged, that is in a large portion of the starting run, viz., in which the tail of the aeroplane can be kept on the ground. The deflection indicated by the pitching clinometer relative to the attitude at rest then gives the longitudinal acceleration, without the necessity of making correction for variations in the attitude of the aeroplane.

The path gradient can be measured in flight by measuring the rate of climb in connection with the speed of flight, or by using a towed path gradient indicator, the wheels being maintained in the attitude as in the first part of the flight.

The third method can be employed with advantage in the assessment of the take-off on an aerodrome situated at some considerable height, where, for the purpose of checking the calculations of disposable acceleration, use is made of more or less reliable data concerning the aeroplane, engine and airscrew.

In order to obtain data in this connection it was proposed to carry out take-offs at sea-level with an over-loaded aeroplane. Reference is made to comparative take-offs of this kind in Chapter 2, (*b*) 10.

3. Application of the C.K.L. Diagram for the Determination of Take-off Paths with a Given Run of Path Gradient (Distance, Height, Time) (*Cf.* Appendix I).

In a given C.K.L. diagram it may be shown graphically what portion of the disposable acceleration is to be used for climbing.

If the selected gradient is, for example, 10 per cent., then a portion of 1 m./sec.^{2}, which is practically 10 per cent. of the acceleration due to gravity is displaced downwards.

If the path gradient remains constant in a speed region, then the line representing the disposable acceleration over that region will be displaced downwards, *cf.* Fig. 3.

1. Determination of the Length of Path (Distance).

By employing a graphical method it is possible in a simple manner to determine the length of path travelled in order to reach a definite speed of flight. In this case use is made of Fig. 4 in which the reciprocal value of the disposable acceleration is plotted against the square of the speed of the aeroplane.

The area of the shaded figure, which is bounded above by this line, is equal to twice the length of path sought (*cf.* Fig. 4). (The accuracy of this is checked by the calculation given in Appendix I.)

In order to make this diagram clearly intelligible it is shown here that a narrow strip extending to a height of $1/a$, that is the inversion of the acceleration, and to a width of one increase in $\frac{1}{2} v^2$ is equal to the increase in length of path.

$$(1/a) \times \text{increase in } \tfrac{1}{2} v^2 = \text{increase in path length.} \quad . \quad . \quad \text{(A)}$$

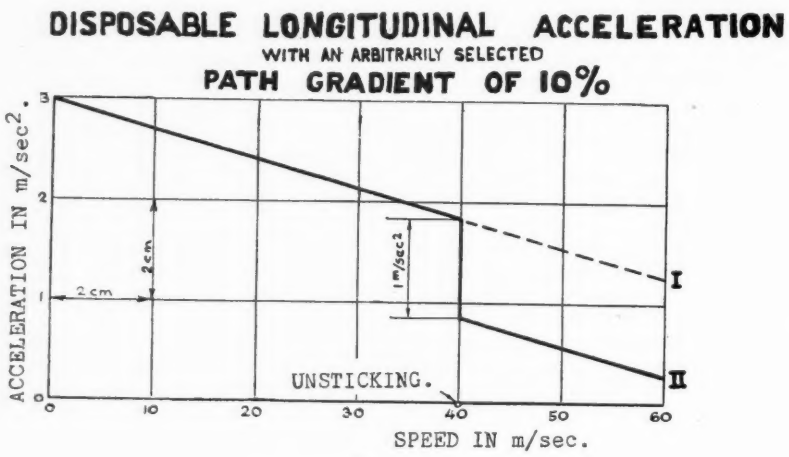
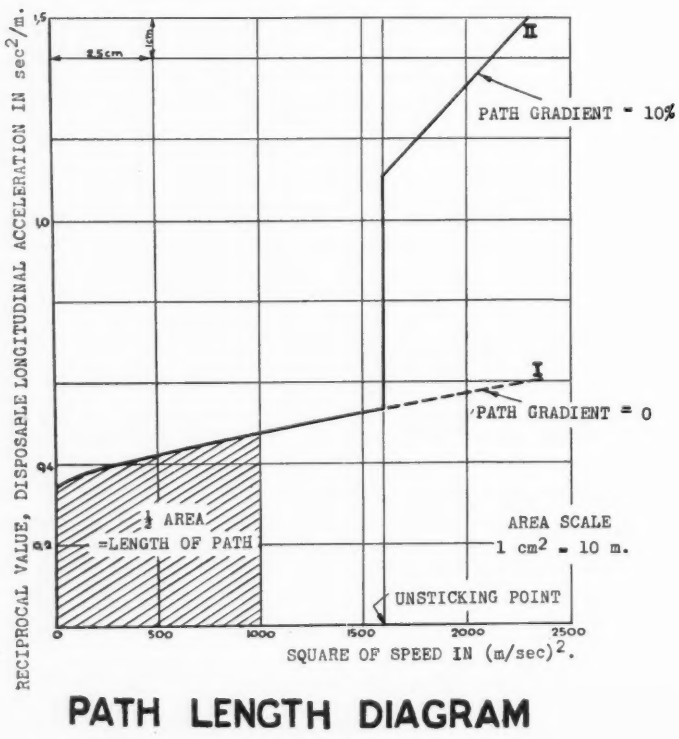


FIG. 3.



PATH LENGTH DIAGRAM

FIG. 4.

TABLE 1a.
CALCULATION OF PATH TIMES.

TABLE 1*a*.

CALCULATION OF PATH TIMES.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		I		II		III		IV		I		II		III		IV	
v	v^2	a	$1/a$	a	$1/a$	a	$1/a$	a	$1/a$	Δt	t	Δt	t	Δt	t	Δt	t
0	0	3.0	0.333	3.0	0.333	3.0	0.333	3.0	0.333	0	0	0	0	0	0	0	0
5	25	2.86	0.35	2.86	0.35	2.86	0.35	2.86	0.35	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
10	100	2.72	0.368	2.72	0.368	2.72	0.368	2.72	0.368	1.8	3.5	1.8	3.5	1.8	3.5	1.8	3.5
15	225	2.58	0.388	2.58	0.388	2.58	0.388	2.58	0 388	1.9	5.4	1.9	5.4	1.9	5.4	1.9	5.4
20	400	2.44	0.410	2.44	0.410	2.44	0.410	2.44	0.410	2.0	7.4	2.0	7.4	2.0	7.4	2.0	7.4
25	625	2.30	0.435	2.30	0.435	2.30	0.435	2.30	0.435	2.18	9.58	2.18	9.58	2.18	9.58	2.18	9.58
30	900	2.16	0.463	2.16	0.463	2.16	0.463	2.16	0.463	2.25	11.83	2.25	11.83	2.25	11.83	2.25	11.83
35	1225	2.02	0.495	2.02	0.495	2.02	0.495	2.02	0.495	2.4	14.23	2.4	14.23	2.4	14.23	2.4	14.23
40	1600	1.88	0.532	1.88 0.90	0.532 1.11	1.88 1.39	0 532 0.720	1.88	0.532	2.55	16.78	2.55	16.78	2.55	16.78	2.55	16.78
45	2025	1.74	0.575	0.76	1.32	1.24	0.806	1.74	0.575	2.75	19.53	6.15	22.93	3.75	20.53	2.75	19.53
50	2500	1.60	0.625	0.62	1.61	1.10	0.91	1.60 1.30	0.625 0.77	3.0	22.53	7.4	30.3	4.25	24.78	3.0	22.53
55	3025	1.46	0.685	0.48	2.08	0.96	1.04	1.16	0.863	3.25	22.78	9.0	39.3	4.8	29.58	4.1	26.63
60	3600	1.32	0.758	0.34	2.94	0.82	1.22	1.02	0.98	3.6	26.38	12.0	51.3	5.6	35.18	4.6	31.23

TABLE 1*b*.

CALCULATION OF PATH LENGTHS AND HEIGHTS.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Midway of interval.	End of interval.		Path Length								Height in m.			
			I		II		III		IV		I	II	III	IV
v^2	v^2	v	sin E=0 %.		sin E=10%.		sin E=5 %.		sin E=3 %.			Case 1.		Case 2.
(m./sec.)^2	(m./sec.)^2	m./sec.	ΔL	L	ΔL	L	ΔL	L	ΔL	L				
100	200	14.4	36	36	36	36	36	36	36	36	0	0	0	0
300	400	20.0	40	76	40	76	40	76	40	76	0	0	0	0
500	600	24.5	42	118	42	118	42	118	42	118	0	0	0	0
700	800	28.3	44	162	44	162	44	162	44	162	0	0	0	0
900	1000	31.6	46	208	46	208	46	208	46	208	0	0	0	0
1100	1200	34.6	48	256	48	256	48	256	48	256	0	0	0	0
1300	1400	37.4	50	306	50	306	50	306	50	306	0	0	0	0
1500	1600	40.0	52	358	52	358	52	358	52	358	0	0	0	0
1700	1800	42.4	54	412	116·5	474·5	73·5	431·5	54	412	0	11.6	3.7	0
1900	2000	44.7	56	468	127·5	602	77·5	509	56	468	0	24.4	7.5	0
2100	2200	46.9	58	526	139	741	81	590	58	526	0	38.3	11.6	0
2300	2400	49.0	60.5	586·5	150	891	85·5	675·5	60.5	586·5	0	53.3	15.9	0
2500	2600	51.0	62.5	649	161	1052	90	765·5	70	656·5	0	69.4	20.4	0.8
2700	2800	52.9	65	714	175	1227	95·5	861	80	736·5	0	86.9	25.2	3.2
2900	3000	54.8	67	781	193	1420	101	962	83·5	820	0	106.2	30.2	5.7
3100	3200	56.5	69	850	215	1635	106	1068	87·5	907·5	0	127.7	35.5	8.3
3300	3400	58.3	71·5	921·5	—	—	112	1180	92	999·5	0	—	41.1	11.1
3500	3600	60.0	74	995·5	—	—	118·5	1298·5	96	1095·5	0	—	46.0	14

If both sides of this equation are multiplied by acceleration and aeroplane mass (*i.e.*, the acceleration force), we find :—

Increase in $\frac{1}{2} mv^2$ = force × increase in path.

This is the work performed by the force. That the latter assertion is correct, follows from the law of the conservation of energy; hence the basis of this construction is correct.

For the Curves I and II in Figs. 1 and 3 the values of the length of path relative to the flight speed attained have been calculated and are given in Tables 1 (*a*) and 1 (*b*).

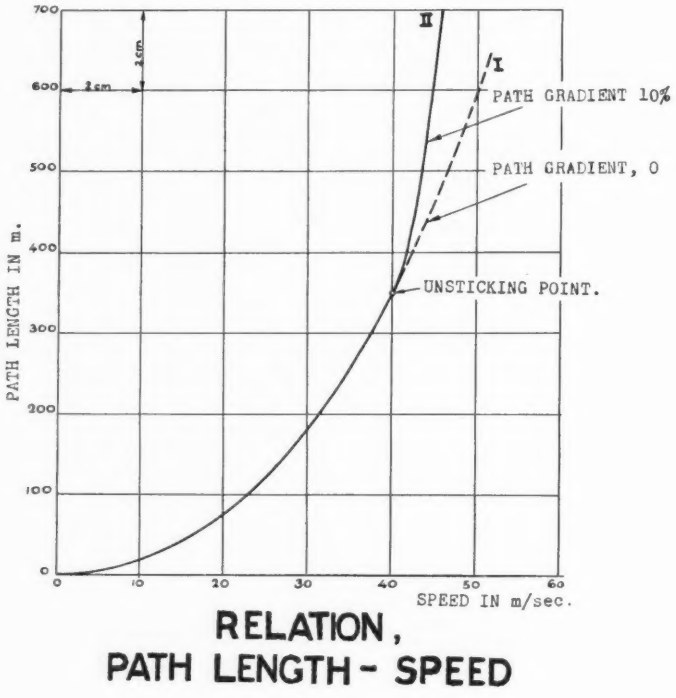


FIG. 5.

The procedure for the calculation is as follows :—

From the C.K.L. diagram, after subtracting the climb component, the disposable acceleration (*a*) is read for a series of speeds (columns 1 and 2). Column 4 contains the values $1/a$.

This inverse acceleration is plotted in Fig. 4 against the square of the speed (v^2), and for the values given in Table 1 (*a*), column 2.

A continuous line is drawn through the points thus found. The value of $1/a$ is read for the mid-points of the *cm* intervals and entered in Table 1 (*b*), column 4.

These values, in accordance with the foregoing equation (A), must be multiplied by the increase $\frac{1}{2} v^2$, viz., here in accordance with figure by 100. The values of $1/a$ read in mm., are therefore given in column 4. They thus give the increase in the length of path in metres per interval, for example, a height of 40 mm. in the figure will indicate an increase of 40 metres in the length of path.

In column 5 these increases have been counted from the initial point, so that the length of path given is that travelled at the end of an interval. The remaining columns contained in these tables are dealt with below.

Fig. 5 shows the lengths of path for lines I and II of Fig. 1 plotted against the speed.

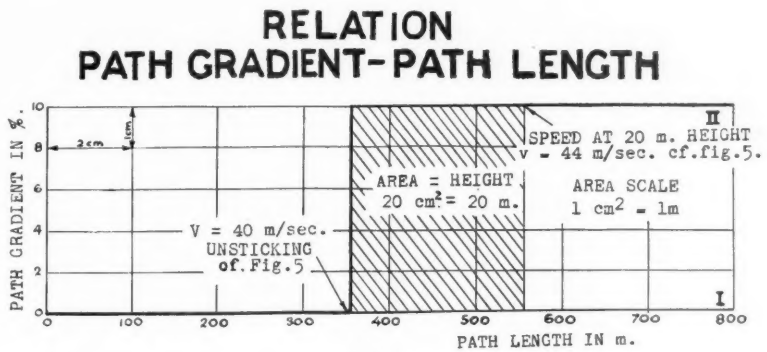


FIG. 6.

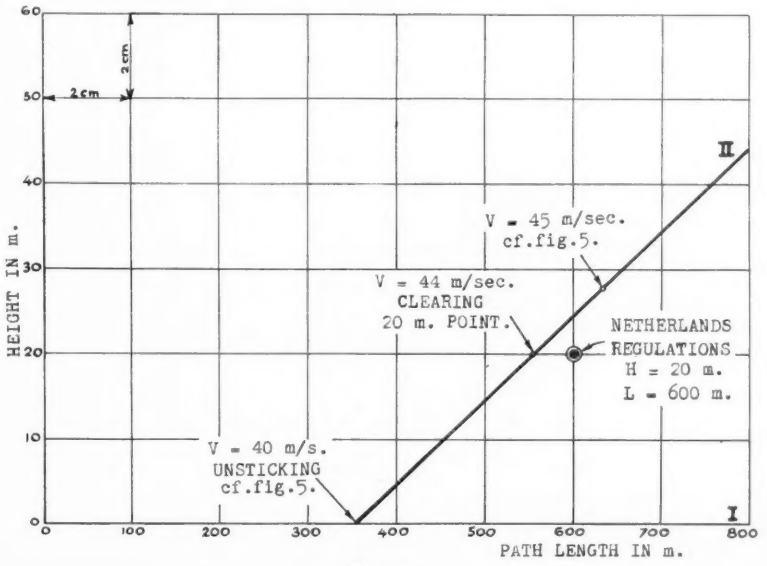


FIG. 7.

II. Determination of the Height.

The increase of the height in an interval is equal to the length of the path interval multiplied by the path gradient. (Increase in height is increase in length of path times path gradient.)

The total height is thus equal to the area contained by the figure bounded by the line of the path gradients plotted against the length of path (*cf.* shaded, Fig. 6).

If the path gradient is constant the height can be readily calculated by multiplying the length of the path, counted from the " unsticking " point, by the path gradient.

In Fig. 7, the flight paths determined in this way are drawn for the path gradients 0 and 10 per cent. (or I and II) concerned.

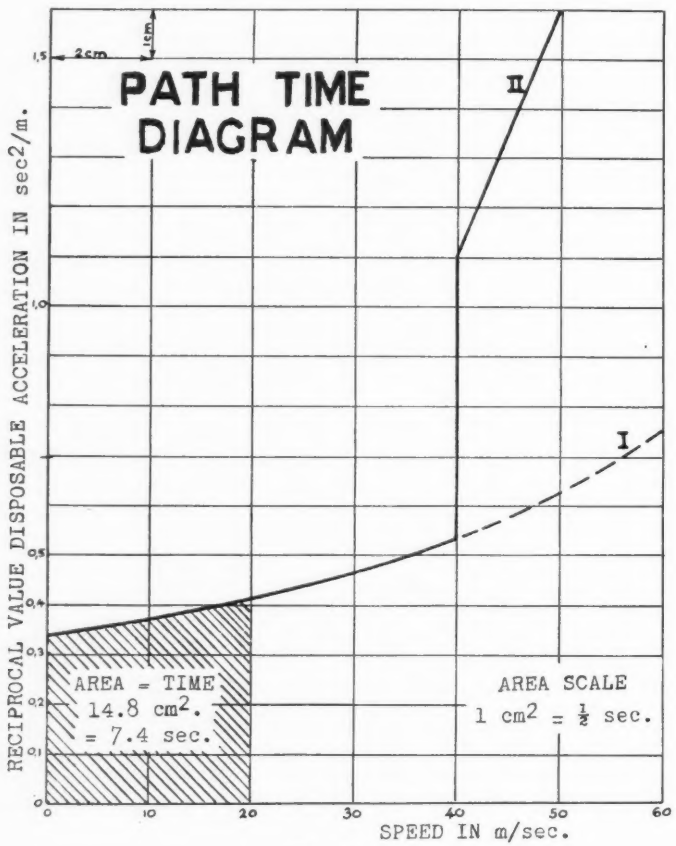


Fig. 8.

III. Determination of the Time.

From the acceleration and corresponding speeds, the time required to attain a definite speed during the accelerated take-off is obtained by a graphical method shown in Fig. 8. By applying a method similar to that employed for the deter-

mination of the path lengths, this figure gives the relation between the reciprocal value of the disposable longitudinal acceleration and the flight speed.

The area of the shaded figure then represents the time.

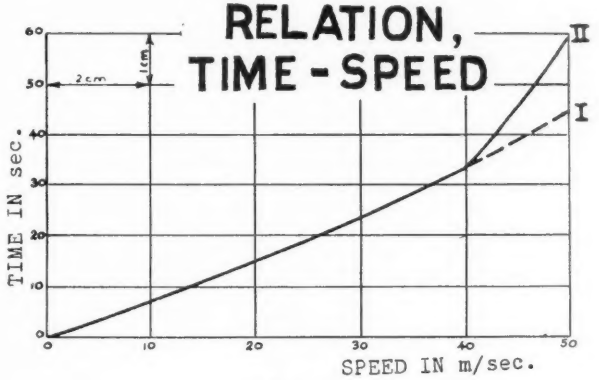


FIG. 9.

This can be readily explained. Namely, a small strip extending to the height of $1/a$ and to the width of one speed increase has an area of increased speed/acceleration.

Now in that short lapse of time the acceleration is assumed as constant, hence equal to the increase in speed divided by this short time.

$$\text{Area of strip} = \frac{\text{incr. speed}}{\text{incr. speed} \div \text{short time period}} = \text{the short time period.}$$

The total area (sum of the strips) is thus equal to the total time, which it was required to ascertain.

The times determined in this way are drawn in Fig. 9 for the path gradients of 0 and 10 per cent.

(*b*) OTHER INFLUENCES.

1. THE PATH GRADIENT.

Consideration has been given to the course of the take-off with different gradients, in other words, when the pilot in each case follows another take-off policy.

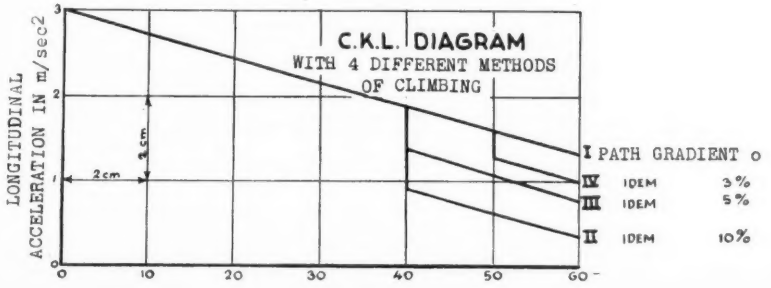


FIG. 10.

The C.K.L. diagram, Fig. 10, contains the figure for the following cases:—

I. *Level take-off.*—The path gradient is constantly zero.

II. *Steep climb.*—Immediately after unsticking, at a speed of $v = 40$ m./sec. (144 km./hr.) the aeroplane climbs with a path gradient of 10 per cent.

III. *Moderate climb.*—The take-off policy is similar to Case II, but now the aeroplane climbs with a path gradient of 5 per cent.

IV. *Gentle climb.*—The take-off policy is again as in the foregoing cases with respect to the unsticking. It is assumed that the pilot only just allows the aeroplane to rise till a speed of $v = 50$ m./s. (180 km./hr.) is reached, after which it changes to a gradient of 3 per cent.

It should be noted incidentally that the values given in Fig. 10 are again the same as for the modern transport aeroplane described in Chapter I (*d*).

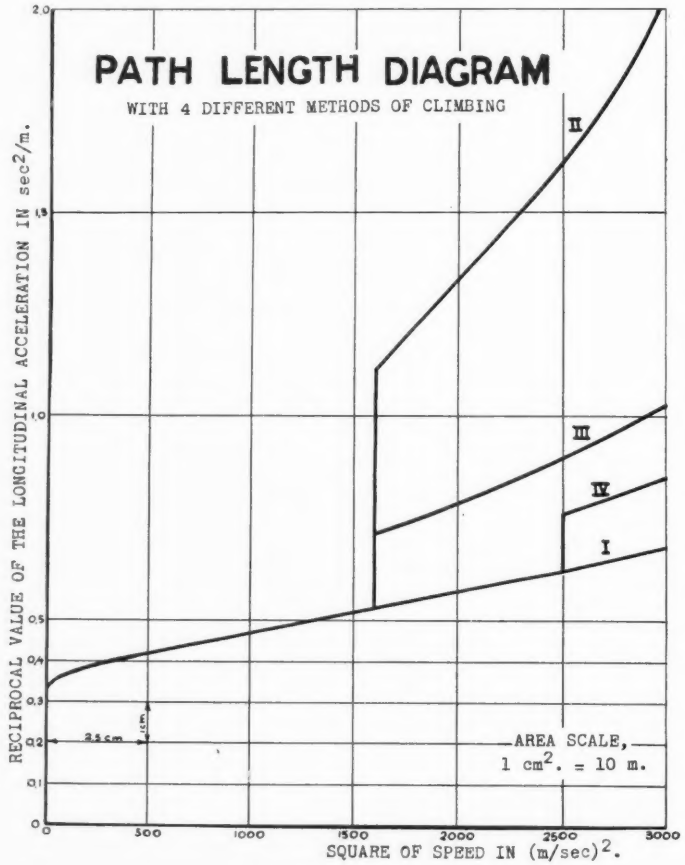


FIG. 11.

The calculated values for length of path, height and time are given in Tables 1 (*a*) and (*b*) and are obtained in the same way as described earlier (Chapter II (*a*) I t/m III).

Fig. 11 gives the lengths of path as determined from the areas, which are plotted in Fig. 12, against the speed.

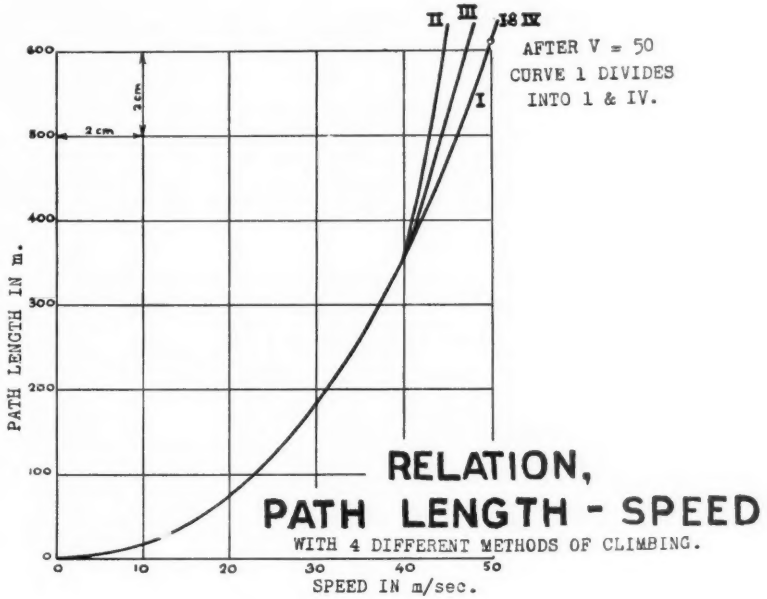


FIG. 12.

The path heights are given in Fig. 13 relative to the lengths of path. The take-off times are obtained from the areas of the path-time diagram given in Fig. 14.

A few values are given in the table below for a speed equal to 50 m./sec. (180 km./hr.).

Case.	Length of path in m. on the ground (starting run).	Time of starting run.	In the air.	Total.	Height in m.	Total take-off time in sec.	Time in vulnerable region in sec.
I.	617	—	—	617	0	$22\frac{1}{2}$	—
II.	358	$16\frac{3}{4}$	608	966	$61\frac{1}{2}$	$30\frac{1}{3}$	$13\frac{1}{2}$
III.	358	$16\frac{3}{4}$	360	718	19.9	$24\frac{3}{4}$	8
IV.	617	—	—	617	0	$22\frac{1}{2}$	—

The influence of the path gradient must be considered in connection with the earlier statements relative to the safety of the take-off (*cf.* Chapter I, Introduction).

It is therefore important to ascertain the extent to which the take-offs fulfil the above-mentioned interpretation of safety, namely, whether a safe speed is reached without the aeroplane finding itself at such a height that, in the event of a sudden disturbance, the flying condition would be rendered unsafe (*cf.* also Chapter I, Introduction *a* and *b*).

Since the consequences of such a disturbance at a low height, for example, of a few metres, say, 3 to 5 m., would not be regarded as serious, the vulnerability

due to low speeds will become a matter of primary importance just at heights greater than the above values.

In the case of the aeroplane for which the figures in the foregoing table have been obtained, a minimum safe speed of 50 m./sec. (180 km./hr.) is considered necessary. The speed on leaving the ground, as has already been mentioned, is 40 m./sec. or 144 km./hr.

Thus, if after unsticking, the aeroplane is made to climb with a sharp path gradient, such as in Cases II and III, then already after covering a length of path of 40 m. or 60 m. respectively, it is outside the above specified safe ground zone without having attained the safe speed. If, however, the path gradient remains below 1.7 per cent. (determined from Fig. 13), then the safe speed is reached on arriving outside the ground zone.

If the aeroplane is made to climb at a speed of more than 40 m./s. but less than 50 m./s., then a larger path gradient may be chosen. For example, at 45 m./s. a gradient of 3 per cent., at 50 m./s. even the largest possible path gradient (16 per cent.).

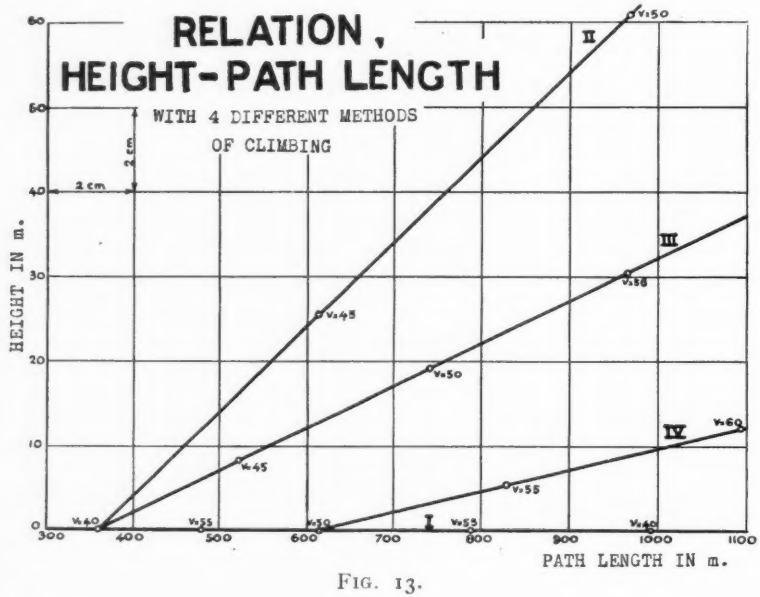


FIG. 13.

In connection with the foregoing, Fig. 15 shows the relation between height and speed. Special attention is directed here to the vulnerable region in the take-off for the climb policies defined under I, II, III, IV.

2. INFLUENCE OF THE AERODROME GRADIENT.

When taking off from an aerodrome which is not horizontal, the slope produces either a retardation or an acceleration, *e.g.*, of 1 per cent. of the acceleration due to gravity with a ground gradient of 1 per cent.

All accelerations are then increased or reduced by an equal amount.

Account is easily taken of this influence in the C.K.L. diagram by correspondingly lowering or raising the ground line.

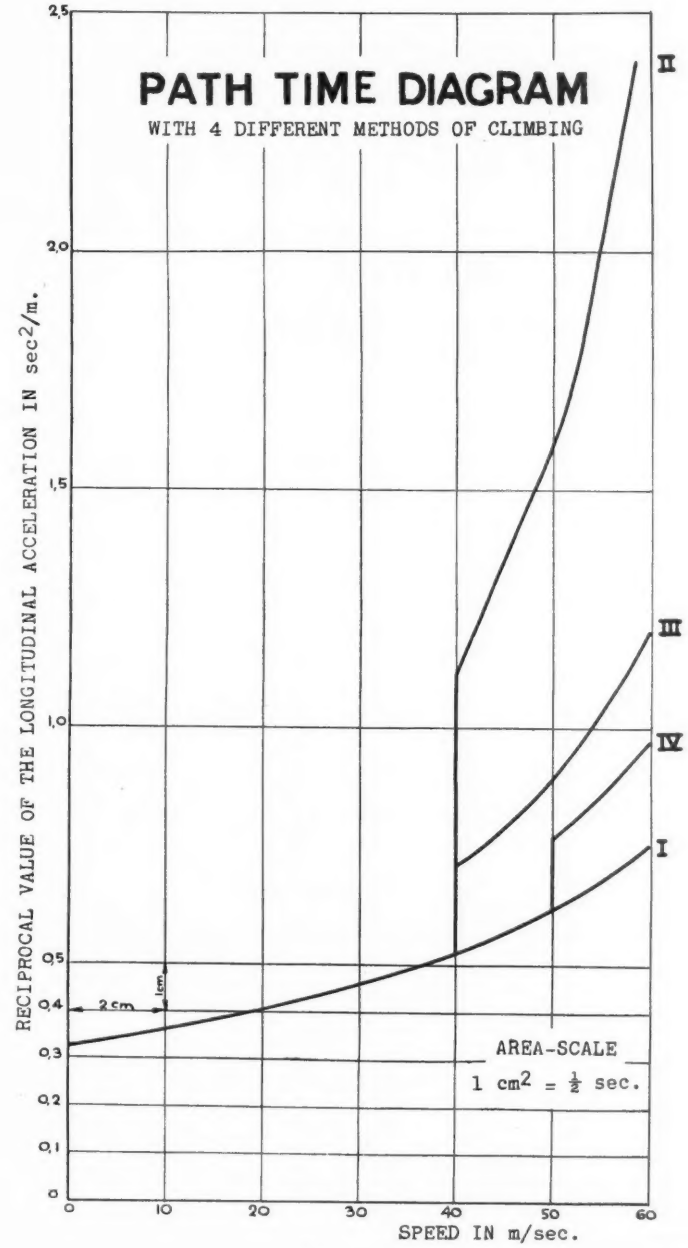

PATH TIME DIAGRAM
WITH 4 DIFFERENT METHODS OF CLIMBING
RECIPROCAL VALUE OF THE LONGITUDINAL ACCELERATION IN sec2/m.
SPEED IN m/sec.
2,5
2,0
1,5
1,0
0,5
0,4
0,3
0,2
0,1
0
0
10
20
30
40
50
60
2cm
1cm
II
III
IV
I
AREA-SCALE
1 cm2 = ½ sec.

FIG. 14.

The path gradient then is not taken relative to the horizontal but to the ground from which the height of the obstructions is calculated.

3. Influence of the Ground Friction.

The friction of the aeroplane when running over the ground reduces the disposable acceleration, and this obviously only during the take-off run when the wheels are in contact with the ground. In order to ascertain the influence of the friction on the take-off, the length of the starting run and the take-off time were determined for two cases of relatively large friction.

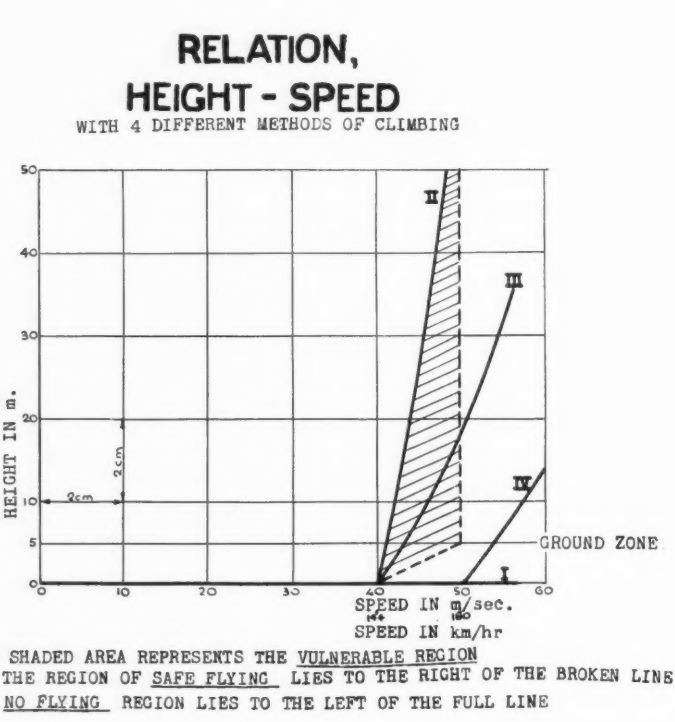


Fig. 15.

The friction coefficient (mu) in the tests referred to was of the normal value of 5 per cent. The cases selected as examples were W 1 with $mu = 10$ per cent. and W 2 with $mu = 15$ per cent., viz., 5 and 10 per cent. respectively greater than the original.

The initial acceleration in case W 1 is thereby reduced by 5 per cent. and in case W 2 by 10 per cent. of the acceleration due to gravity.

In the determination of the disposable acceleration it is assumed that during the starting run the lift of the wings is proportional to the square of the speed, so that the wheel load and hence the friction diminishes gradually (parabolically) from the maximum value to zero at the moment of leaving the ground.

This is shown graphically in the C.K.L. diagram of Fig. 16. The calculated values, also of the reciprocal values of the acceleration and of the take-off times are given in Tables II, III and IV.

TABLE II.

CALCULATION OF THE INFLUENCE OF GROUND FRICTION ON ACCELERATIONS.

		Symbol.	I		W_1		W_2	
		Δ mu	0		0.05		0.10	
v	v^2	sin E	0		0		0	
m./sec.	(m./sec.)^2		a	$1/a$	a	$1/a$	a	$1/a$
0	0		3.0	0.333	2.51	0.402	2.02	0.495
5	25		2.86	0.35	2.38	0.420	1.90	0.526
10	100		2.72	0.368	2.26	0.442	1.80	0.555
15	225		2.58	0.388	2.16	0.463	1.74	0.575
20	400		2.44	0.410	2.08	0.481	1.73	0.578
25	625		2.30	0.435	2.00	0.500	1.70	0.588
30	900		2.16	0.463	1.95	0.513	1.73	0.578
35	1225		2.02	0.495	1.90	0.526	1.77	0.565
40	1600		1.88	0.532	1.88	0.532	1.88	0.532
45	2025		1.74	0.575	1.74	0.575	1.74	0.575
50	2500		1.60	0.625	1.60	0.625	1.60	0.625

TABLE III.

CALCULATION OF THE INFLUENCE OF GROUND FRICTION ON PATH LENGTHS.

Midway of interval.	End of interval.		Symbol.	I		W_1		W_2	
			Δ mu	0		0.05		0.10	
v^2	v^2	v	sin E	0		0		0	
(m./sec.)^2	(m./sec.)^2	m./sec.		ΔL	L	ΔL	L	ΔL	L
100	200	14.4		36	36	44	44	54	54
300	400	20.0		40	76	$47^{\cdot 5}$	$91^{\cdot 5}$	58	112
500	600	24.5		42	118	49	$140^{\cdot 5}$	59	171
700	800	28.3		44	162	50	$190^{\cdot 5}$	59	230
900	1000	31.6		46	208	51	$241^{\cdot 5}$	58	288
1100	1200	34.6		48	256	52	$293^{\cdot 5}$	57	345
1300	1400	37.4		50	306	53	$346^{\cdot 5}$	56	401
1500	1600	40.0		52	358	53	$399^{\cdot 5}$	$54^{\cdot 5}$	$455^{\cdot 5}$
1700	1800	42.4		54	412	54	$453^{\cdot 5}$	54	$509^{\cdot 5}$
1900	2000	44.7		56	468	56	$509^{\cdot 5}$	56	$565^{\cdot 5}$
2100	2200	46.9		58	526	58	$567^{\cdot 5}$	58	$623^{\cdot 5}$
2300	2400	49.0		$60^{\cdot 5}$	$586^{\cdot 5}$	$60^{\cdot 5}$	628	$60^{\cdot 5}$	684
2500	2600	51.0		$62^{\cdot 5}$	649	$62^{\cdot 5}$	$690^{\cdot 5}$	$62^{\cdot 5}$	$746^{\cdot 5}$

TABLE IV.

CALCULATION OF THE INFLUENCE OF GROUND FRICTION ON TIMES.

Midway of interval.	End of interval.	I		W_1		W_2	
v	v						
m./sec.	m./sec.	Δt	t	Δt	t	Δt	t
2.5	5	1.7	1.7	2.05	2.05	2.55	2.55
7.5	10	1.8	3.5	2.15	4.2	2.7	5.25
12.5	15	1.9	5.4	2.25	6.45	2.8	8.05
17.5	20	2.0	7.4	2.35	8.80	2.9	10.95
22.5	25	2.18	9.58	2.45	11.25	$2.9^{\cdot 5}$	13.9
27.5	30	$2.2^{\cdot 5}$	11.83	2.55	13.8	2.9	16.8
32.5	35	2.4	14.23	2.60	16.4	$2.8^{\cdot 5}$	$19.6^{\cdot 5}$
37.5	40	$2.5^{\cdot 5}$	16.78	2.65	19.65	2.75	22.4
42.5	45	$2.7^{\cdot 5}$	19.50	2.75	21.8	2.75	25.15
47.5	50	3.0	22.53	3.0	24.8	3.0	28.15

The corresponding path length diagram is given in Fig. 17. The path lengths thus obtained are plotted in Fig. 18 against the speed.

It is seen that the starting run is increased from 358 to 400 m. and 455 m. respectively with this greater friction, that is, an increase of 12 and 27 per cent. respectively. This 12 per cent. is included in the assumed values given in the table of possible extensions of the take-off lengths (*cf.* Chapter I (*d*)).

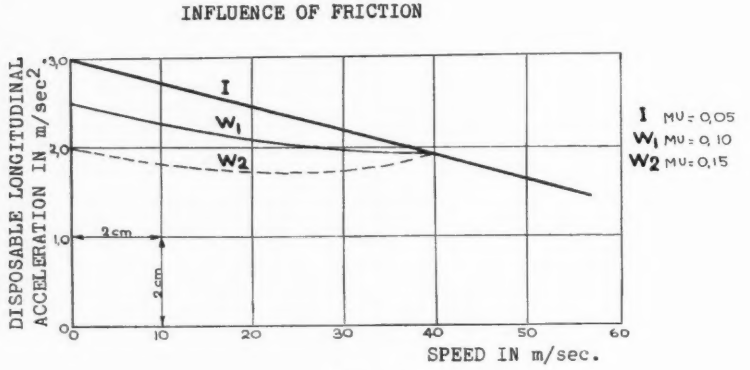


FIG. 16.

C.K.L. with two example curves relative to the influence of ground friction.

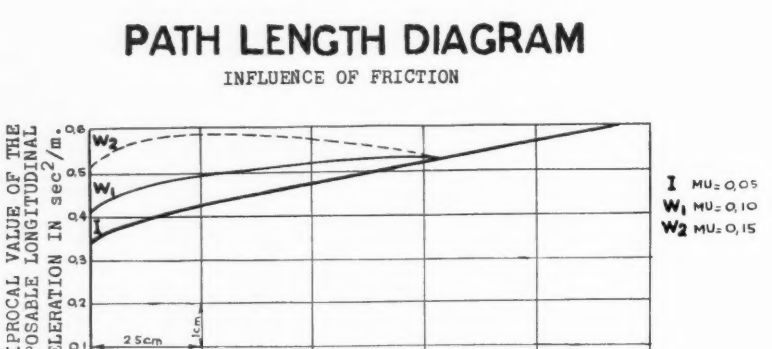


FIG. 17.

Path length diagram with two example curves relative to the influence of ground friction.

4. INFLUENCE OF REDUCED ENGINE OUTPUT.

In the event of a reduction of the engine output such as may be caused by a small disturbance in the ignition, the acceleration becomes smaller. In the calculation in Appendix III it is shown that the relative decrease in the mean acceleration is approximately 1.4 times as great as the relative decrease of the engine power (or of the ratio: engine power to aeroplane weight). It is assumed here, that at every speed the thrust is proportional to the engine power. In the

path length diagram therefore all values of the reciprocal acceleration are greater (the enclosed figure becomes higher).

When the engine output becomes reduced k per cent., the length of path increases by 1.4 times k per cent. (*cf.* Fig. 22*c*).

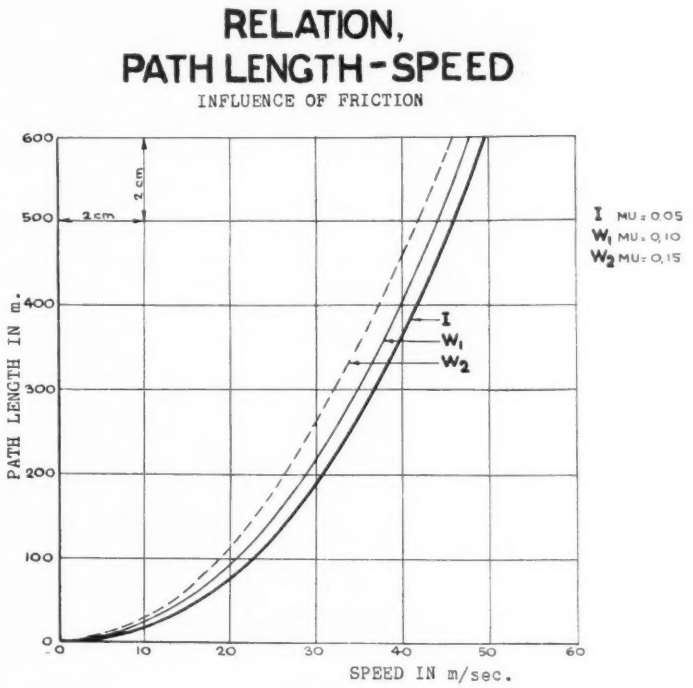


FIG. 18.

Relation between path length and speed with two example curves relative to the influence of ground friction.

5. INFLUENCE OF VARIATIONS IN THE WEIGHT OF THE AEROPLANE.

With an increase in the weight of the aeroplane the acceleration is diminished, calculated for points with the same flight speed.

In the calculation in Appendix III it is shown that the relative reduction of the mean acceleration is approximately 1.4 times as great as the relative increase of the weight of the aeroplane. The safe speed to be acquired increases with the weight, and in such a way, that the square of the speed increases by the same percentage as the weight of the aeroplane.

In the path length diagram, therefore, the line of the reciprocal acceleration is moved to a higher value of v^2. In this way a vertical strip is added. The mean value of $1/a$ thereby becomes still slightly greater. The factor of 1.4 referred to above is therefore raised to 1.5 (eventually to 1.6).

The area of the figure in the path length diagram therefore increases by 2.5 to 2.6 times the relative increase of the weight (*cf.* Fig. 22*d*).

6. INFLUENCE OF AIR TEMPERATURE AND AIR PRESSURE.

As a result of a high temperature or a low air pressure, both the engine output and the density of the air become reduced.

Owing to the decrease in the engine output, the propulsive force of the airscrews and hence the acceleration of the aeroplane are lessened.

That the safe speed is higher in the less dense air is seen from the following consideration.

The safe condition of an aeroplane depends on the angle of incidence and hence also on the dynamic pressure under which it is flying.

This pressure remains constant when the square of the speed (v^2) increases in the inverse proportion to the air density. With a 10 per cent. reduction of the density, v^2 increases by 10 per cent. and hence the safe speed (v) by 5 per cent. The unsticking speed then likewise increases by 5 per cent.

Thus in the path length diagram there is an increase both in the height of the enclosed area owing to the reduction of the acceleration and also in the width owing to the increase of the speeds.

The decrease in the engine output due to varying atmospheric conditions can be found by corrections which are determined from engine measurements.

The following influence is assumed by many test experts and by the Wright engine firm.

The engine output decreases by the same percentage as the value of the air pressure below normal and by half the percentage of the value of the absolute temperature above 288° (or 15°C.).

A decrease of 5 per cent. in the output is therefore found with a difference of 5 per cent. in the air pressure, viz., 38 mm. on 760 mm., hence with the barometer at 722 mm. or with an increase of 10 per cent. in the absolute temperature. This gives a temperature of $288 + 29 \approx 317°$ abs. or 44°C.

In the first case the speeds are increased by $2\frac{1}{2}$ per cent., in the second by 5 per cent. The useful effect of the airscrew is assumed approximately as dependent on the speed only. This assumption is justified in particular when adjustable airscrews are used, the r.p.m. of which is constant. Hence at any speed the airscrew thrust varies proportionally with the output. This thrust is used partially to overcome the resistance of the aeroplane (friction + air resistance); hence the free acceleration decreases relatively more than the engine output. In the case of the aeroplane under consideration, the decrease is roughly $1\frac{1}{2}$ times as great (*cf.* Appendix III).

The increase in the length of path is therefore $7\frac{1}{2}$ per cent. greater owing to the 5 per cent. reduction of the engine output, and in addition as much greater owing to the increase of the speeds, as has been determined above due to low pressure or high temperature. The increase in the path length is seen to be 13 per cent. with the 5 per cent. reduced pressure and 18 per cent. with 10 per cent. excess temperature.

The increase in the time of the starting run is calculated in an entirely similar manner. The results are given together with those obtained for the increased lengths of path in the following table:—

REVIEW OF THE VARIATIONS DUE TO ABNORMAL ATMOSPHERIC CONDITIONS.

Pressure.	Air Temp.	Density.	Engine Output.	Acceleration.	Take-off Speed.	Length of Path.	Time
−5% (722 mm.)	Normal	−5%	−5%	$-7\frac{1}{2}$%	$+2\frac{1}{2}$%	+13%	+10%
Normal	+10% (44°C.)	−10%	−5%	$-7\frac{1}{2}$%	+5%	+18%	+13%

In the foregoing considerations only the main factors have been taken into account.

Secondary factors have not been dealt with.

These include the change which would be produced in the variation of the blade angle with the speed when the take-off is made in rarefied air with ordinary

adjustable airscrews. This variation would be slightly different in abnormally warm air than in air of low pressure, for the same engine output.

The influence on the airscrew thrust, however, is found to be negligible.

Engines with Limited Intake Pressure.

Attention should be drawn to the running of engines, the intake pressure of which under normal atmospheric conditions is higher than is considered safe for the good running of the engine in the take-off. In such cases a low barometric pressure would then give rise to a lower intake pressure and thus a lower engine output, when a certain difference occurs in the normal air pressure (760 mm. Hg.). In this region the gas admission must only be slightly closed in order to obtain the permissible intake pressure.

Owing to the lower exhaust pressure and presumably owing to the resulting improved scavenging of the cylinders in the exhaust period, the engine output itself in this region will be slightly greater than in standard (normal) air.

This increase, however, will be left out of consideration. In calculating the take-off of aeroplanes fitted with engines with such a limitation of the intake pressure, the following rule should be observed.

The correction owing to abnormal atmosphere remains unchanged.

Only in the case where the air is rarer, due exclusively to a low barometric pressure does the acceleration remain the same as in normal air, so that no correction need be applied to the height of the surface in Figs. 4 and 11 or 8 and 14 respectively. The increase in the speeds due to the rarer air, however, must always be taken into account.

This therefore gives a relative increase in the length of the take-off equal to the relative decrease of the air density.

The Wright Cyclone engine, type F.62, may be quoted as an example.

In accordance with the K.L.M. specifications the throttle may only just be opened full in standard air at a height of 412 metres with a corresponding pressure of 723 mm. Hg.

Should the air pressure be of this value at ground level, the engine would be capable of giving practically its full output, whilst at normal temperature the air density would be 5 per cent. less than normal.

The acceleration of the aeroplane with corresponding indicated speeds (air speeds) will be the same.

The take-off length will then be increased (as v^2) by 5 per cent. (*cf.* Fig. 22*f*).

7. Influence of the Wind.

(*a*) Uniform Wind Velocity.

The influence of the wind, when the aeroplane takes off against the wind, is now considered. In the first place the increase in the wind velocity with height will be left out of consideration. It should be noted that this influence is favourable, since it brings about an apparent increase of the disposable acceleration.

The variation in the wind velocity concerned is relatively the greatest at the beginning of the take-off. The aeroplane therefore need not be accelerated in order to obtain a speed relative to the air equal to that of the wind. With large flight speed the effect of the wind is relatively less.

In order to introduce this influence into the graphical determination of the length of path (Fig. 4), wind factors are determined by which the values of the ordinates ($1/a$) must be multiplied.

This factor is $1 - (\text{wind velocity/flight speed}) = 1 - w/v$.

In this connection, " flight speed " is defined as the speed of the aeroplane relative to the air, also in the region when the aeroplane is still running on the ground.

The method of determination of the wind factor is shown in Appendix II.

The factors and the lengths of path are determined for the wind velocities: $w = 2.5$, 4 and 8 m./sec. or 9, 14.4 and 28.8 km./hr. respectively. The values for 2.5 m./s. have been taken in order to conform to standard conditions.

When taking-off with the wind following, the wind factor is greater than unity (viz., $1 + w/v$).

The wind factors and the values of $1/a$ multiplied by them are shown graphically in Figs. 19 and 20. The path lengths are likewise plotted in Fig. 21 against v^2.

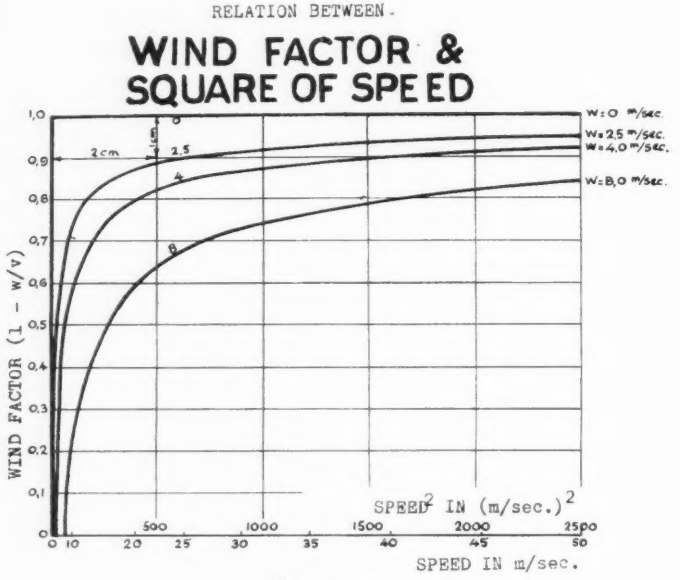


FIG. 19.

They give slightly curved lines, not so strongly curved as the parabolic curve of Fig. 5 where the path length is plotted against the speed itself.

The table below gives the numerical values of the *path lengths* in metres.

Wind velocity (m./s.)	0	2.5	4	8
Speed attained 40 m./sec. (144 km./hr.) ...	358	317	291	238
Speed attained 50 m./sec. (180 km./hr.) ...	620	565	530	447

The decreases in the path length due to head wind are given below as percentage values of the length of path with no wind.

Wind velocity (m./s.)	2·5	4	8
	Reduction in length.		
Speed attained 40 m./s. (144 km./hr.) ...	11.5%	18.7%	34.4%
Speed attained 50 m./s. (180 km./hr.) ...	8.9%	14.5%	28%

The wind has little influence on the take-off time.

This time is reduced only by the time required to impart to the aeroplane from rest in still air, a speed equal to the wind velocity. From Fig. 9 the time velocity diagram, it is seen that these times, for the wind velocities considered are as follows:—

Wind velocity	0	2.5	4	8 m./sec.
Shortening of take-off time	0	0.8	1.3	2.7 sec.

For purposes of comparison it may be said that the time necessary to obtain a speed of 40 m./s. in still air is 16.8 sec. The time of take-off varies relatively

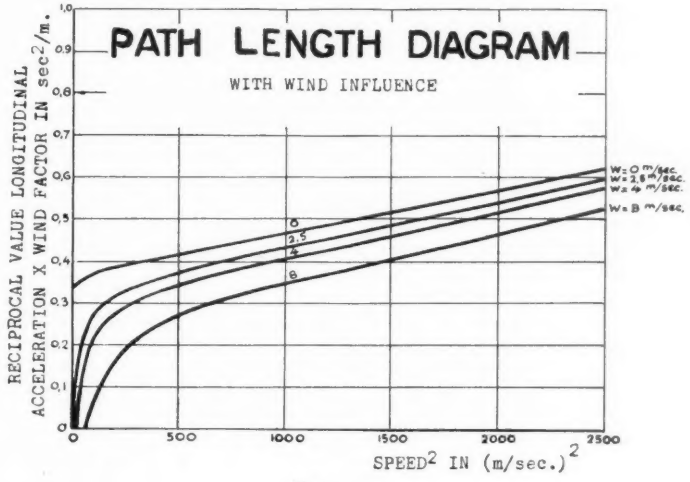


FIG. 20.

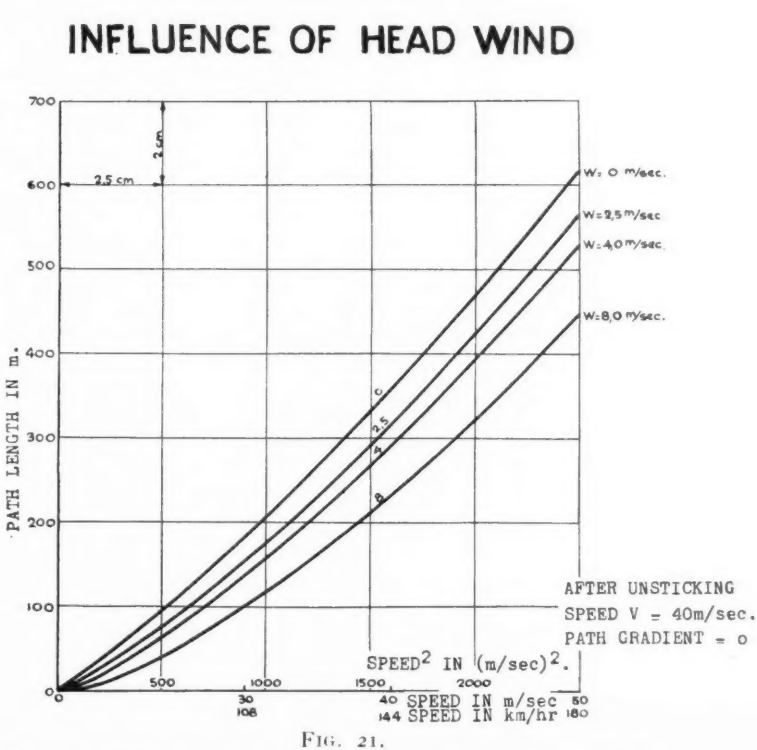


FIG. 21.

Relation between path length and (speed)² with wind influence.

less than the length of path. Namely, the aeroplane passes through practically the same speed range, but is not sensibly restrained owing to the head wind during the accelerated movement.

(*b*) Influence of the Increase in the Wind Velocity with Height.

When climbing, the aeroplane encounters a wind velocity which increases in strength. This corresponds to a secondary acceleration which may be added to the acceleration to which the aeroplane is subjected as a result of the thrust of the airscrew relative to the air.

The calculation is given in Appendix II (*b*).

It is seen that this acceleration is proportional to the rate of climb of the aeroplane and to the increase of the wind velocity with the height (A. II (*b*), equation 1).

This increase in velocity is proportional to the wind velocity (measured at a height); it is greatest immediately above the ground, but becomes small at greater distances from the ground (*cf.* equation 2 and column 5 in Table V).

Table V.

Influence of Head Wind.

End of interval.		Midway of interval.		Wind Factor (f)			
v^2	v	v^2	v	$w=$	$w=$	$w=$	l/a
(m./sec.)^2	m./sec.	(m./sec.)^2	m./sec.	2·5 m./sec.	4 m./sec.	8 m./sec.	sec.^{2}/m.
200	14.4	100	10.0	0.75	0.60	0.20	0.368
400	20.0	300	17.3	0.85·5	0.769	0.54	0.40
600	24.5	500	22.4	0.888	0.821	0.65	0.42
800	28.3	700	26.4	0.905	0.849	0.70	0.44
1000	31.6	900	30.0	0.917	0.867	0.73	0.46
1200	34.6	1100	33.2	0.92·5	0.879	0.75·5	0.48
1400	37.4	1300	36.0	0.93	0.889	0.77·5	0.50
1600	40.0	1500	38.7	0.93·5	0.897	0.79	0.52
1800	42.4	1700	41.2	0.939	0.903	0.80·5	0.54
2000	44.7	1900	43.6	0.943	0.908	0.81·5	0.56
2200	46.9	2100	45.8	0.94·5	0.913	0.82·5	0.58
2400	49.0	2300	47.9	0.948	0.916·5	0.83·5	0.60·5
2600	51.0	2500	50.0	0.950	0.920	0.84	0.62·5

$w=2.5$ m./sec.			$w=4$ m./sec.			$w=8$ m./sec.		
f/a	ΔL	L	f/a	ΔL	L	f/a	ΔL	L
0.276	24	24	0.221	16	16	0.074	6	6
0.342	34	58	0.308	30	46	0.216	21	27
0.373	37	95	0.345	34·5	80·5	0.273	27	54
0.398	40	135	0.374	37·5	118	0.308	31	85
0.422	42	177	0.399	40	158	0.336	33·5	118·5
0.444	44·5	221·5	0.422	42	200	0.362	36	154·5
0.465	46·5	268	0.445	44·5	244·5	0.388	39	193·5
0.486	49	317	0.466	46·5	291	0.411	41	234·5
0.507	51	368	0.488	49	340	0 435	43·5	278
0.528	53	421	0.508	51	391	0.456	45·5	323·5
0.548	55	476	0.530	53	444	0.478	48	371·5
0.574	57·5	533·5	0.555	55·5	499·5	0.505	50·5	422
0.594	59·5	593	0.575	57·5	557	0.525	52·5	475

This " wind acceleration " has been worked out for certain values of the height above the ground, for a path gradient of 1/10, for flight speeds of 40, 45 and 50 m./sec.; whilst the wind velocity, measured at 3 metres above the ground is assumed as 4 and 8 m./sec. respectively.

For the variation of the wind velocity with height, use is made of the Prandtl v. Kármán formula, according to which the velocity is proportional to the one-seventh root of the height.

It is seen that with a strong wind ($w=8$ m./sec. or 28.8 km./hr.), the wind acceleration at a height of 2 to 4 metres may attain a value of 1 to 2 m./sec.^{2} in

the case of a rapid rate of climb. This is a good deal when compared with the acceleration, which, according to the C.K.L. diagram for the modern transport aeroplane under consideration decreases from 3 to 1.6 m./sec.^{2} between flight speeds of 0 and 50 m./sec.

From this it follows that the increase in the wind velocity with height may perceptibly increase the acceleration, whereby the take-off path is shortened and hence the take-off is rendered slightly safer.

When making measurements, this influence of the wind may give rise to considerable disturbance, one more reason why the aeroplane should be kept at a low height above the ground.

8. Influence of Proximity to the Ground on the Drag of the Aeroplane.

The down flow of the air in the case of a wing becomes smaller when a wing approaches the ground and yet the lifting force is maintained constant. The result is that the resistance of the aeroplane is smaller at a small height above the ground. It is not the frictional resistance which becomes smaller, but the so-called " induced resistance " which affects the whole flow configuration.

In recent times, particularly in Japan, theoretical and experimental investigations have been carried out in this region, on models of tapered wings and whole aeroplane models (*cf.* Tokyo Reports Nos. 156 and 158).

It is seen that at a small height the induced resistance may be halved.

9. Influence of the Height of the Aerodrome.

The safe start increases in length at a high level owing both to the reduced engine power and to the necessary increase of the speed associated with the smaller air density. For moderate heights the methods given above may be applied.

At a high level the calculations must be worked out more closely since with the smaller accelerations the effect of small inaccuracies in the assumptions of aeroplane resistance is much greater. The C.K.L. diagram as a whole must be corrected according to the heights of the aerodrome. Multiplication by an increment factor known only as a rough approximation would lead to large errors at greater heights.

For such reduction reference should be made to published works, in which particulars may be found for the available engine power from the height-power diagrams given by the engine makers. (Handbook of Aeronautics.)

For a medium height, viz., 500 metres a value of 12.5 per cent. is found for the increase in length of path, in the European standard atmosphere and 14 per cent. in the Indies standard atmosphere, compared with 0m. height in normal European conditions.

10. Survey of the Various Influences.

In the foregoing chapters an account is given of the consequences resulting from departures from the normal condition for each of the various factors mentioned, so that now the influences of some of these factors may be compared one with the other. For this purpose the path length diagrams for the cases referred to below are given in Fig. 22.

In a few cases the result is a reduction of the longitudinal acceleration only, viz., a path length diagram which is " raised " only. These cases include:—

(*a*) Slope of the aerodrome where the aeroplane takes off uphill.
(*b*) Ground friction greater than that assumed as normal.
(*c*) Engine output less than that given as normal.

Another case leads to a broadening of the path length diagram, whereby all speeds due to the reduction of the air density are increased, *e.g.*, the unsticking and the safe speed for obtaining the corresponding lift factor. This applies to

the case where the atmospheric pressure is below the normal, when for the engine with " limited intake " no lower intake pressure is obtained.

Other cases produce an increase in both the height and the width of the path length diagram. These are:—

(*d*) Increased weight of the aeroplane.

(*e*) High atmospheric temperature and (or) low atmospheric pressure, when in the engine with " unrestricted intake " also a lower intake pressure is obtained.

Figs. (*d*) and (*e*), however, are not the same.

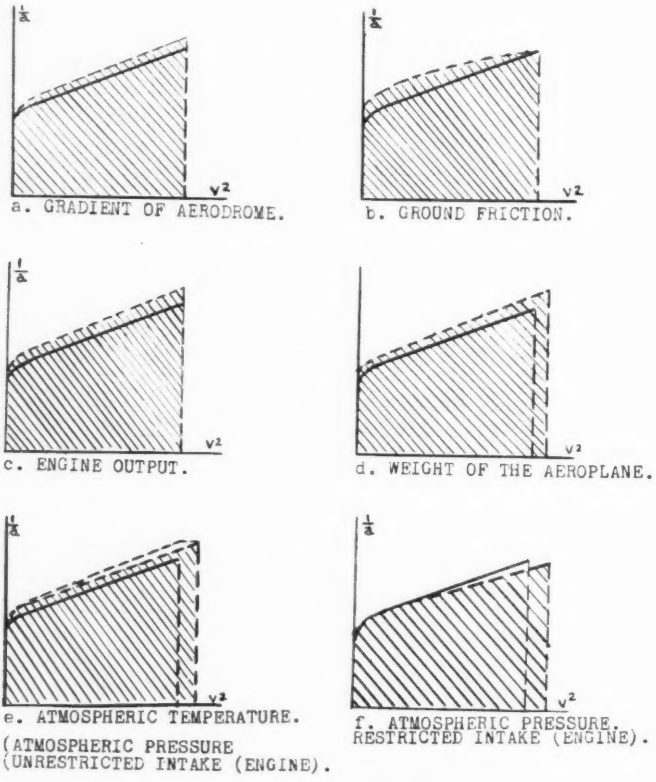


FIG. 22.

In case (*d*), both the safe speed and the safe pressure head are increased. With the latter there is a corresponding decrease in the airscrew thrust, hence a higher value of the reciprocal value of the longitudinal acceleration ($1/a$).

In case (*e*) with unfavourable atmospheric conditions no (or practically no) smaller airscrew thrust is produced in the transition to the increased speed, since the same pressure head is attained. The diagram is thus expanded towards the right.

This comparison has a practical significance since take-off tests may be undertaken with an increased aeroplane weight in order to produce a condition approximately equivalent to that obtained in rarefied air, such as may be found, for example, at an aerodrome situated at a high level.

In this connection, namely, account ought to be taken of both the increase in the height and the width of the diagram. Thus, as a general rule the reaction of output of the engine to the rarefaction of the air would not be proportional to the air density so that the height and width of the diagram would not increase in the same measure. This is at variance with the influence of an increased weight (*cf.* (*d*)).

Further, in the case of a comparative test of this kind, only such flights should be compared, in which the same measure of safety is obtained.

This test can be carried out also in normal atmosphere in the following manner:—

The engine output which would be available at the height of the aerodrome concerned is determined from the engine specifications. This reduced output, according to the same engine curves, can also be obtained in normal air by limiting the intake pressure.

The take-off measurement for the determination of the modified C.K.L. diagram is now carried out with the lower output and up to the higher speeds which would be produced in the rarefied air at the aerodrome situated at the high altitude.

The take-off length diagram will then be enlarged in both width and height in the same measure as that corresponding to the take-off at the high altitude aerodrome.

In order to obtain conditions equivalent to the so-called " Indies " conditions, the method described here may be used with advantage owing to the fact that the high atmospheric temperature affects the density of the air in a greater measure (nearly twice as much) than the engine output.

In this way the desired comparative test may be made at less cost and risk. This can be clearly appreciated in view of the fact that no increase in weight is necessary and that the pilot, by running the engine at full throttle can always obtain the condition of the normal take-off.

In (*f*) the case is represented of lower atmospheric pressure, when the engine intake pressure, *i.e.*, the engine output remains constant (with adjustable airscrews). The original path length diagram is thus not increased in height, only expanded towards the right.

To this series the case is further added of a head wind (*g*), whereby the take-off length is reduced.

The various cases discussed here are again summarised in the table on p. 713 where (*k*) represents the variation as a percentage value.

The remaining figures are not to be taken as exact; they are intended only to provide a general indication.

The combination of different disturbing factors would as a rule have more serious consequences than the sum of the consequences as such, as may be seen from the graphical result obtained when these combined influences are introduced in the C.K.L. diagram.

Appendix I.

1. Graphical Determination of the Length of the Take-off.

(*a*) Determination of the length of path (s), when the relation between the acceleration (a) and speed (v) along the path is given.

According to definition the acceleration is the derivative of the speed with respect to the time :—

$$a = dv/dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

For this we may write :—

$$a = (dv/ds)\,(ds/dt) = (dv/ds)\,v \quad . \quad . \quad . \quad . \quad (2)$$

$$ds = vdv/a = (1/a)\,d\,(v^2/2) \quad . \quad . \quad . \quad . \quad (3)$$

$$S = \tfrac{1}{2}\int_0^v (1/a)\,d\,(v^2) \quad . \quad . \quad . \quad . \quad . \quad (4)$$

By integration in steps the following relations hold :—

$$s = (\tfrac{1}{2})\,(1/a)\,\Delta v^2 \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

$$s = \tfrac{1}{2}\,\text{sum}\,(\Delta v^2/a) \quad . \quad . \quad . \quad . \quad . \quad (4a)$$

In Fig. 4, $1/a$ is plotted as ordinate against v^2 as abscissa.

(*b*) The proof referred to in Chapter II (*a*) 3 is obtained from the relation :—

$$\Delta s = (1/a)\,\Delta v^2/2,$$

both terms being multiplied by $P = ma$, the acceleration force :—

$$P\Delta s = m\Delta v^2/2 = \Delta\,(\tfrac{1}{2})\,mv^2.$$

The first term represents the work performed by the acceleration force over the element of path ΔS, the second term represents the increase in the work capacity due to the motion of the aeroplane, which are equal to each other in accordance with the law of the conservation of energy. The initial assumption is therefore correct.

2. Determination of the Height (*h*).

The angle of the path gradient (elevation) is given by the angle E.

The path gradient $\sin E = dh/ds$.

The length of path S is measured along the sloping path, so that

$$dh = \sin E ds \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$h = \int_0^s \sin E ds \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

or approximately

$$h = \text{sum}\,\sin E\Delta s \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

In the example with constant values of the path gradient $\sin E = 0.05$ and 0.10 respectively we find

$$h = 0.05\ s \text{ and}$$

$$h_2 = 0.10\ s \text{ respectively.}$$

With variable gradient the height is the content of the figure in the diagram, in which $\sin E$ is plotted against s (*cf.* Fig. 6).

3. Determination of the Time (*t*).

In accordance with the definition

$$a = dv/dt \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

so that

$$dt = dv/a \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

$$t = \int_0^v (dv/a) \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

By integration by steps, approximately

$$t = \text{sum}\,(1/a)\,\Delta v \quad . \quad . \quad . \quad . \quad . \quad (3a)$$

In Fig. 8, $1/a$ is plotted against v. The area of the shaded figure is equal to the time required in order to acquire a speed of 20 m./sec. That the dimensions are in agreement is seen from the product of the dimensions of the co-ordinates $(\text{sec.}^2/m) \times (m/\text{sec})$, which gives seconds or time.

Appendix II.

Influence of the Wind.

(*a*) No Increase in the Wind Velocity with Height.

The symbol v is used for the flight speed, *i.e.*, the speed relative to the wind, also when the wheels are still supporting in the first part of the take-off. The speed relative to the ground is denoted by v_g.

For the path relative to the air, the symbol s is maintained; for the path relative to the ground, s_g. As the path gradient is slight, any differences measured along the path and with respect to the horizon, *i.e.*, parallel to the wind velocity, is neglected.

Hitherto the path lengths have been calculated in still air.

The length relative to the ground was the same as that along the path measured relative to the air.

In order to ascertain the safety in flying over an aerodrome obstruction, the ground lengths (S_g) must now be deduced from the path lengths (s). For the speeds, the relation

$$v_g = v - w \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

holds.

Since $ds = vdt$ and $ds_g = v_g dt$,

$$ds_g = (1 - w/v)\,.\,ds \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The path elements relative to the ground are found from the elements relative to the air by multiplying these by $f = 1 - w/v$, the wind factor.

Applying the graphical method described in Chapter II (*a*) 3, the values of $1/a$ are now multiplied by the wind factor (*cf.* Table V and Fig. 20).

In Fig. 19 the calculating wind factors are plotted against v^2, which = 0 for $w = v$ and approaches unity asymptotically for large values of v.

The values selected are $w = 2.5$, 4 and 8 m./s., that is, 0.0625, 0.1, and 0.2 times the unsticking (flying) speed respectively.

The path lengths are calculated in the diagram (Fig. 20) in which f/a is plotted against v^2. The strips represent intervals of v^2. In order to determine the area of these strips the value is calculated for the mid-point of the v^2 interval. The f/a curve exhibits a marked curvature only in the first strip; this is taken into account in the determination of the area.

The further calculation follows from Table V.

The values of the calculated path are plotted in Fig. 21 against the values of v^2 which hold for the end of each interval ($v^2 = 200$, 400, etc.).

The path lengths are = 0 for the wind velocities dealt with here with $v^2 = 0$, 6.25, 16 and 64 $(\text{m./sec.})^2$ respectively.

(*b*) Influence of the Increase in the Wind Velocity with Height.

The relative acceleration of the air with respect to the aeroplane (a_w) and vice versa is expressed as wind acceleration gradient (variation of wind velocity with height) and rate of climb of the aeroplane.

$$a_w = dw/dt = (dw/dh)\,(dh/dt) = (dw/dh)\,.\,v \sin E \quad . \quad . \quad (1)$$

In words, the wind acceleration is equal to " wind variation " times rate of climb.

If the relation of the wind velocity with the height is expressed in the usual form by $w = ch^n$, where n is put as 1/7 according to Prandtl-v. Kármán, then

$$dw/dh = (1/7) \cdot (1/h^{6/7}) \cdot (w_1/\sqrt[7]{h_1})$$

where w_1 denotes the wind velocity measured at the normal height h_1.

In test flights, the measurement height (h_1) adopted is 3 metres above the ground; this velocity is given by w_3. With $\sqrt[7]{3} = 1.17$ we find

$$dw/dh = 0.122\ (w_3/h^{6/7}) \quad . \quad . \quad . \quad . \quad (2)$$

Substituting (2) in (1) we obtain for the wind acceleration:—

$$a_w = 0.122\ (w_3/h^{6/7}) \cdot v \sin E \quad . \quad . \quad . \quad . \quad (3)$$

Table VI contains the values of a_w for the heights $h = 1$, 2, 4, 8, 16 and 32 metres determined for the wind velocity $w_3 = 4$ and 8 m./sec. The values assumed for the flight speed are 40, 45 and 50 m./sec. and for the path gradient $\sin E = 0.10$.

The highest values of the "wind acceleration" a_w are found at the smallest height and with the highest flight speed, namely, the particularly large value of 4.88 m./sec.^{2}.

Appendix III.

Influence of Change in the Engine Output and Weight of the Aeroplane on the Take-off.

Although these two influences can be dealt with separately, this has not been done here, since it is seen from a more general formula that they are entirely similar.

The airscrew thrust P_s reduced by the drag of the aeroplane cG is equal to the acceleration force P.

$$P = P_s - cG$$

in which G is the weight of the aeroplane and c a drag co-efficient.

In order to obtain non-dimensional quantities the "relative acceleration" $a/g = a_1$ is introduced, that is, the quotient of aeroplane acceleration and acceleration due to gravity.

Both terms of (1) are divided by G.

$$P/G = (P_s/G) - c \quad . \quad . \quad . \quad . \quad . \quad (2a)$$

Since $P = ma$ and $G = mg$,

$$P/G = a/g = a_1.$$

Putting $(P_s/G) = y$, (1a) becomes

$$a_1 = y - c \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

y is the ratio of airscrew thrust to aeroplane weight, an abstract quantity which with a given flight speed is assumed as proportional to the engine output and inversely proportional to the weight. In this quantity, therefore, both the influence of the atmosphere and the variations of the weight are expressed; y is the relative acceleration of the aeroplane when its drag (and hence also c) is zero.

In the first place let us see how the relative variation of a_1 depends on the other quantities. It is assumed that the drag coefficient is practically constant.

By differentiation of (2) we find

$$da_1 = dy \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

dividing by a_1

$$da_1/a_1 = dy/a_1 = (dy/y)(y/a_1) \quad . \quad . \quad . \quad . \quad (3a)$$

with $y = a_1 + c$, in accordance with (2) this gives

$$da_1/a_1 = (dy/y)\{(a_1 + c)/a_1\} \quad . \quad . \quad . \quad . \quad (4)$$

The relative or percentage variation of the value a_1 is thus equal to that of y (the thrust-weight ratio), but multiplied by a factor greater than unity.

Table VI.

Determination of the Wind Acceleration Due to the Increase of the Wind Velocity with Height.

Column	1	2	3	4	5	6	7	8	9	10	11
Conditions		Flight Speed v in m./sec.				40	45	50	40	45	50
,,		Wind Velocity w in m./sec.				4	4	4	8	8	8
Quantity	Height	log h	$6/7$ log	$h\,h^{6/7}$	$0.122\,h^{6/7}$	Wind Acceleration a_w.					
Unit	m.	—	—	—	—	m./sec.^{2}	m./sec.^{2}	m./sec.^{2}	m./sec.^{2}	m./sec.^{2}	m./sec.^{2}
Calculation	—	—	$6/7 \times (2)$	—	$0.122/(4)$	$16 \times (5)$	$18 \times (5)$	$20 \times (5)$	$32 \times (5)$	$36 \times (5)$	$40 \times (5)$
	1	0.00000	0.000	1.00	0.122	1.95	2.20	2.44	3.91	4.40	4.88
	2	0.30103	0.258	1.81	0.0674	1.04	1.17	1.30	2.08	2.34	2.60
	4	0.60266	0.516	3.28	0.0372	0.59·5	0.67	0.74·5	1.19	1.34	1.49
	8	0.90309	0.774	5.94	0.0206	0.33	0.37	0.41	0.66	0.74	0.82
	16	1.20412	1.032	10.78	0.0113	0.18	0.204	0.226	0.36	0.408	0.45
	32	2.50515	1.290	19.50	0.00626	0.10	0.113	0.125	0.20	0.226	0.25

Table showing Various Influences.

Case and letter as in Fig. 22.	Variation in	Abs. temp.	Air Pressure.	Engine output.	Weight.	Mean acceleration	Air density	Sq. of safe speed.	Length of path.
a	Slope of aerodrome	norm.	norm.	norm.	norm.	$-1.4k$	norm.	norm.	$+1.4k$
b	Ground friction	,,	,,	,,	,,	$-1.3k$	,,	,,	$+1.3k$
c	Engine output	,,	,,	$-k$	,,	$-1.4k$	,,	,,	$+1.4k$
d	Weight of aeroplane	,,	,,	,,	$+k$	$-1.5k$	,,	$+k$	$+2.5k$
e	Air temperature	$+k$	,,	$-\frac{1}{2}k$	norm.	$-0.7k$	$-k$	$+k$	$+1.7k$
,,	Air pressure (unrestricted intake)	norm.	$-k$	$-k$	,,	$-1.4k$	$-k$	$+k$	$+2.4k$
f	Air pressure (restricted intake)	,,	$-k$	norm.	,,	norm.	$-k$	$-k$	$+k$
g	Head wind	,,	norm.	,,	,,	$+k^1$	norm.	norm.	$-k^1$

k = variation in %

At the beginning of the take-off, a_1 is at its highest value, 0.3, namely, six times the value of the normal friction co-efficient of $c =$ " mu " 0.05.

The factor is then $7/6 = 1.17$.

On attaining a high speed, *e.g.*, 50 m./sec., a_1 becomes $= 0.16$, $c =$ drag/lift $=$ approx. 0.07.

The factor then becomes

$$(a_1 + c)/a_1 = 0.23/0.16 = 1.44.$$

In the case of the aeroplane under consideration, therefore, it would not be far wrong to put the mean factor 1.4 for the take-off as a whole, so that

$$da_1/a_1 = 1.4\, dy/y.$$

If the airscrew thrust or y is reduced by 5 per cent., the mean acceleration is then reduced by 1.4×5 per cent. $= 7$ per cent. By reducing the weight of the aeroplane by 5 per cent. the acceleration will be correspondingly increased by 7 per cent.

Let us now see how far atmosphere and aeroplane weight affect the *safe speed* to be attained. The *aim* is, however, to fly at such an angle of incidence or with such a lift co-efficient, (c_a) that the stability of the air flow is ensured.

In this connection no account is taken of the influence of the temperature on the viscosity of the air and hence of the Reynolds scale number, as being of secondary importance.

This lift coefficient is the quotient of the mean wing pressure Q and the dynamic pressure q.

$$c_a = Q/q = (G/F)/\{(\tfrac{1}{2})\rho v^2\} \quad . \quad . \quad . \quad . \quad (5)$$

When the density of the air (ρ) only varies, the same safe lift coefficient can be obtained by equal and opposite relative variation of v^2, with the same aeroplane weight.

From $v^2 =$ const. we get

$$d\rho/\rho = -d(v)^2/v^2 \quad . \quad . \quad . \quad . \quad . \quad (6)$$

If the weight of the aeroplane is varied, the same value of c_a can be obtained by a similar relative variation of v^2.

With $G/v^2 =$ const. we have

$$dG/G = d(v^2)/v^2$$

The points of equal c_a are obtained with a safe percentage reduction of the air density or a similar increase of the aeroplane weight.

ABSTRACTS FROM THE SCIENTIFIC AND TECHNICAL PRESS.

Issued by the
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(Prepared by R.T.P.)

No. 70. AUGUST, 1939.

A New Anti-Aircraft Range Finder Training Device—Distance of Shell Burst from Target. (From the German.) (Rivista Aeronautica, Vol. 15, No. 5, May, 1939, pp. 331/334.) (70/1 Germany.)

The training device consists of two cine theodolites situated at the ends of a known base. Target and shell burst are photographed simultaneously on the two cine films which also show the altitude and azimuth of the corresponding telescope axis.

These films are transferred to a special electrical calculating machine which gives in a few seconds the space distance as well as the co-ordinates Δx, Δy, Δz of the shell burst relative to the target.

As the films can be rendered available very quickly, it is possible to inform the gun crew as to the accuracy of fire within a few minutes of other exercise.

The Penetration of Bombs and Projectiles (from the German). (La Technique Moderne, Vol. 31, No. 8, 15/4/39, p. 293.) (70/2 Germany.)

If reinforced concrete (compression strength 200 kg./cm.^{2}) is struck by a shell moving at 450 m./sec., the depth of penetration is five times the calibre of the shell, for shells between 75 and 420 mm. calibre.

The depth of penetration of thin cased bombs at a striking velocity of 300 m./sec. is given in the following table (same concrete as above).

Weight of Bomb (kg.)	Penetration (cm.)
50	45
100	55
300	80
1,000	125
1,800	150

For soft steel, the penetration is $\frac{1}{5}$ of the above, whilst for sand, the penetration is multiplied by 10.

Incendiary Bombs made of Electron (from the German). (La Technique Moderne, Vol. 31, No. 8, 15/4/39, p. 293.) (70/3 Germany.)

A large bombing aircraft can carry over 2,000 of these small incendiaries. They are dropped from special containers at the rate of 10 or 20 a time. On account of the light weight and shape of these bombs, the terminal velocity is low (80 m./sec.) and the dispersion large.

The nose of these bombs is very flat and stability is assured by a terminal rod 8 cm. long. The charge consists of thermite which will burn 40-50 sec. (without oxygen). The heat liberated melts the electron case which burns for 10-20 minutes. The pressure generated by the burning thermite may project portions of the molten casing for a distance of 17 m.

A bomber flying at 1,700 m. at a speed of 320 km./h. and discharging 20 bombs every second on a 15 per cent. built-up region will start a fire on every path of 20-25 m.^{2} unless suitable measures of protection are taken, such as a steel plate 6 mm. thick, a single layer of sandbags (well compressed) or a layer of reinforced concrete 10 cm. thick.

Some Lessons of the Spanish War. (V. Usera, U.S. Naval Inst. Proc. Vol. 65, No. 437, July, 1939, pp. 969-972.) (70/4 U.S.A.)

The author served as a captain with the Spanish Government Forces and he attributes the ultimate success mainly to the better discipline of Franco's Force brought about mainly by a preponderance of efficiently trained officers and non-commissioned officers.

As regards aerial warfare, the author considers that even a poorly entrenched unit with inadequate anti-aircraft guns cannot be driven out by plane alone if the men are of average morale. The aeroplane, despite its definite limitation and lack of accuracy, is still, however, a new enough weapon to be terrifying even to seasoned soldiers. There is a tendency to stop fire and watch for the drama to follow. If the attacking infantry is well trained, this temporary lull can be taken advantage of to close up within assault distance and attack immediately the planes are withdrawn The precious moments of temporary shock and demoralization are thus utilised fully. Although this appears obvious, the author experienced the greatest difficulty when leading an attack to prevent his men watching the supporting aircraft rather than carrying on the attack.

Lessons of the War in Spain. (Laurent-Eynac, L'Air, No. 473, 20/7/39, p. 445.) (70/5 France.)

In the past, exaggerated claims have been made in turn for each new weapon as it has been introduced. We need only mention the torpedo and the high explosive shell.

The issue of a war is decided by the correct combination of all weapons, and whilst the Spanish conflict was not decided by the air force alone, it is correct to say that it could not have been won without it.

The successful blockade of the Mediterranean coast has demonstrated that the seaplane can in many respects replace the submarine in the destruction of merchant shipping, whilst the active part played by assault planes in ground engagements shows how modern aircraft constitutes a new danger to the infantry and gives the effect of an artillery bombardment without being tied to fixed emplacements.

It is, however, in the penetration behind the lines that the air force introduces a new factor. In Spain this form of attack has not played a large role, mainly because at the start of this war, not sufficient aircraft were available on either side.

In a large scale continental war, however, it is certain that attacks by large quantities of aircraft, well trained and knowing exactly their objectives, would profoundly affect the early stages of mobilisation and thus possibly determine the issue. Suitable protection against such " lightning " strokes presents the first problem and the author regrets that more attention is not paid in his country to modern anti aircraft artillery (88, 37 and 20 mm. calibre) such as utilised by the Nationalist troops in Spain with great success.

Tendencies and Aims of Italian Aviation. (Gen. Valle, Les Ailes, No. 944, 20/7/39, p. 6.) (70/6 Italy.)

The Italian Under Secretary of State for Air, General Valle, in a speech to the Senate reiterates his faith in the decisive role which the aircraft will play in any future war. Neither the Army nor the Navy can dispense with help from the air. The air force, however, on its own can put the enemy into a desperate position if the material is good and handled resolutely. The fact that certain parts of Valencia, Barcelona and Madrid are still intact was entirely a question of policy. Moreover, the number of aircraft engaged was relatively small. Spain can give no conception of what would happen if the number of aircraft engaged were increased 50 fold and no quarter given.

According to General Valle the following should be the objectives of aerial attacks in the order of their vulnerability: (1) centres of population; (2) fuel stores; (3) factories; (4) merchant ships; (5) harbours; (6) warships; (7) aerodromes; (8) railways; (9) trenches.

In connection with fuel stores, the speaker stressed the point that 30,000 tons of petrol were set on fire in Valencia as the result of a single attack with 50 kg. bombs. According to him, the fuel stored in Italy is safe from any air attack.

A New German Gas-Operated Light Machine Gun "Knott-Bremse" 7.92 mm. Calibre. (W.T.M., Vol. 43, No. 7, July, 1939, pp. 289-293.) (70/7 Germany.)

Nearly 80 per cent. of all the governments have adopted gas operated machine guns, the remaining 20 per cent. utilising recoil operation. This choice appears to be mainly due to the easier manufacture of the gas operated gun, recoil operation only being adopted by states which possess a highly developed armament industry.

Gas operated guns usually tap the gas from a position in the barrel. In the "K.B." gun a special muzzle attachment is used, the gas for operating the gun thus being only utilised after the projectile has left the barrel. As a result the muzzle velocity is not affected. Specially bladed channels are provided for conducting the gas to the piston operating the breech, which constitutes the only moving element, the barrel being stationary (air cooled). The barrel is easily removed by means of a special handle, an exchange being recommended after 200-500 rounds depending on rate of fire.

Everything is at rest during the actual firing process and the muzzle attachment is shaped to act as a recoil brake. As a result the gun is very steady during operation and more than 20,000 rounds can be fired by one gunner without undue fatigue. The gun weighs 9 kg. and can fire up to 1,000 rounds per minute (muzzle velocity 750 m./sec.). Three photographs.

The Accuracy of A.A. Artillery. (W.T.M., Vol. 43, No. 7, July, 1939, p. 331.) (70/8 Italy.)

Experience in the Spanish war has shown that an average of 15 shots suffices to bring down aircraft operating at 4,000 m.

Errors in acoustical spotters are mainly due to insufficient training of the operators. In these instruments it does not pay to increase the base beyond 3 m. The range can be increased by electrical amplification.

Of great importance is proper training of the observer and in this connection special apparatus has been devised which enables the pupil to check the accuracy of his observations.

As is well known, the blind generally possess very acute hearing and this has led to their extensive enrolment for this kind of work in Italy.

Finally, the position of the acoustic spotter in relation to the nature of the surrounding terrain is of the greatest importance.

Experimental Investigation of the Translatory Motion of Vortex Rings in a Real Fluid. (C. H. Krutzsch, Ann. der Physik., Vol. 35, No. 6, July, 1939, pp. 497-523.) (70/9 Germany.)

The vortices were produced in a water tank by the controlled motion of a piston in a tube communicating with the tank.

The vortex was rendered visible by painting the edge of the tube with an alcoholic solution of various dyes. (Sodium fluorescine or malachite green). The colouring matter enters the boundary layer ultimately forming the vortex and very beautiful photographs were obtained by the author, either showing the complete ring from the front or a section of the ring under lateral illumination. In the latter case the colouring matter was applied to the top and bottom edge of the tube only. During its progress the original circular shape of the vortex develops indentations and finally breaks up. The main cause of this instability is the introduction of fresh material into the vortex from the outside fluid, whilst in the ideal case, the vortex consists permanently of the same fluid particles. The correctness of the interpretation is shown by photographing the motion of fluid particles through which the ring passes. The resultant instability follows from a complicated interaction of the forces due to viscosity, pressure and centrifugal action.

A more complete investigation of the velocity distribution in the vortex will form the subject of a subsequent paper.

Experimental Investigation of the Momentum Method for Determining Profile Drag. (H. J. Goett, N.A.C.A. Tech. Report No. 660, 1939.) (70/10 U.S.A.)

An experimental investigation has been carried out in the full scale wind tunnel to determine the accuracy of the Jones and Betz equations for computing profile drag from total and static pressure surveys in the wake. The surveys were made behind 6 × 36 foot aerofoils of N.A.C.A. 0009, 0012 and 0018 section at zero lift and behind N.A.C.A. 0012 at positive lifts. Various spanwise positions were used, the distance behind the aerofoils ranging from .05c to 3.0c. The following are the main conclusions:—

1. The Betz and Jones equations give practically identical results, and, since the latter gives rise to simpler computation, it is recommended.
2. The drag by the momentum method is practically independent of distance over the range investigated. This answers the point raised by Muttray (L.F.F. Vol. 14, pp. 371-372, Air Ministry Translation No. 500).
3. At zero lift the drag by the momentum method agrees with balance measurements within 2 per cent.

A direct comparison between drag results obtained by momentum and balance measurements of a lifting aerofoil is impossible because of failure of the momentum method near the tip, and the inclusion of induced drag in the balance results. If the induced drag is deduced from the balance tests, its difference from the momentum drag gives the tip drag. The author's experiments show that the difference increases from 1 per cent. at zero lift to 22 per cent. at $C_L = 1$. It is, however, not certain that the whole of this difference is due to tip effects.

The Growth of the Circulation of an Aerofoil Flying Through a Gust. (W. R. Sears and A. M. Kuethe, J. Aeron. Sci., Vol. 6, No. 9, July, 1939, pp. 376-378.) (70/11 U.S.A.)

The rate of increase of the circulation about the tip of a wing flying through a vertical gust has been determined experimentally by Kuethe (N.A.C.A. Tech. Note 685).

The same phenomenon has been investigated theoretically by von Kármán and Sears (Aerofoil theory for non-uniform motion, J. Aeron. Sci., Vol. 5, No. 10, pp. 379-390) and by Jones (N.A.C.A. Tech. Note. 682).

The authors carry out a comparison between theory and experiment and show that fairly good agreement exists with the Kármán-Sears two dimensional theory.

The measured growth of circulation is, however, less rapid than that predicted by Jones. Possible explanations of the discrepancy are:—

(i) Jones theory is based on a lifting line approximation which can be shown to over-estimate the effect for small values of t.

(ii) Kuethe's measured rise may be too small due to experimental errors known to be present.

The Two-Dimensional Hydrodynamical Theory of Moving Aerofoils (III). (R. M. Morris, Proc. Roy. Soc., Series A, Vol. 172, No. 949, 3/8/39, pp. 213-230.) (70/12 Great Britain.)

This paper follows two previous ones on the general hydrodynamical problem of the two-dimensional motion of a cylinder in inviscid incompressible fluid. The general formulæ obtained in these papers are here reduced for the special case of the Joukowski aerofoil, where the coefficients assume simple finite forms. The formulæ obtained are then applied to a determination of the lift, moment and centre of pressure in uniform rectilinear motion, and also to a discussion of the dynamics of the small oscillation about such rectilinear motion. A simple condition is then obtained for the stability of this rectilinear motion, showing the effects of thickness, camber and angle of attack on this important property of the aerofoil.

De Havilland Variable Pitch Airscrew (Part 4). (Machinery, 15/6/39, pp. 321-329) (Metropolitan Vickers Technical News Bulletin No. 666, 23/6/39, p. 1.) (70/13 Great Britain.)

This article concludes the series dealing with the production of the components for variable pitch air screws by Messrs. de Havilland Aircraft Co. Ltd. The grinding of the counterbore and of the cam sleeve is discussed and also the other operations on the cam sleeve such as drilling and milling of the cam slots. The next operation is cutting the teeth in the inner cam sleeve and broaching the slots in the spider. The collar at the root of the blade is moulded, after fabrication, from bakelite-impregnated discs and tape.

Illustrated with 14 photographs and two diagrams.

Flight Tests on the Range of the Kôken Long-Range Monoplane. (H. Kimura and T. Takatuki, Aer. Res. Inst., Tokyo, Report No. 175, May, 1939, pp. 129-148.) (70/14 Japan.)

The range, kilometres per kilogram of fuel, of the Kôken long-range monoplane was measured for several speeds in level flight at heights between 1,000 m. and 2,000 m. The total weight at the tests was from 5,000 kg. to 6,000 kg., *i.e.*, from 55 to 65 per cent. of the fully loaded weight.

The test results with undercarriage retracted agree fairly well with those calculated from the wind-tunnel test data for C_z/C_x and η and the bench test data for the fuel consumption, so we can estimate, by the extrapolation of the curve of the calculated results, the range at the most economical speed, which was not actually measured in the tests.

With undercarriage retracted, the Kôken long-range monoplane, fitted with the wooden propellers, can cruise distances of 3.9 and 3.3 km. per kg. of fuel at total weights of 5,000 and 6,000 kg. respectively and altitudes of 1,000-2,000 m.; when fitted with a variable-pitch propeller, 5 per cent. increase is obtained on the above figures of range.

The test results showed that by pulling down the undercarriage the range decreased about 20 per cent. over the weight and speed range tested accompanied by an appreciable decrease of the economical speed due to the shifting of the incidence angle of maximum lift-drag ratio to a higher value.

Assuming, from the wind tunnel tests, a propeller efficiency of 79 per cent., the maximum lift-drag ratio of the aircraft is of the order of 19.

Flight Tests of Retractable Ailerons on a Highly Tapered Wing. (J. W. Wetmore, N.A.C.A. Tech. Note, No. 714, June, 1939.) (70/15 U.S.A.)

A flight investigation was conducted to determine the lateral-control characteristics of retractable ailerons installed on a highly tapered wing. The effectiveness of the ailerons in producing roll was measured at various air speeds with full-span plain flaps both neutral and deflected 45°. The direction of the yawing moment created by the ailerons was also noted.

The lateral control provided by the retractable ailerons used in this investigation was approximately the same as that obtained with the plain ailerons of equal span with which the aeroplane was previously equipped. The amount of control available was found to be somewhat inadequate, apparently because of the rather short span of the ailerons (0.327 of the wing span). It is likely that, with an aileron span of from 0.50 to 0.60, a satisfactory degree of control would be obtained. With the full-span flaps deflected 45°, the rolling action of the ailerons was increased about 30 per cent. over that obtained with the flaps neutral at the same speed. The yawing moment produced by the ailerons was in the same sense as the rolling moment, *i.e.*, right roll was accompanied by right yaw. Lag in the response of the rolling action to control application was not large enough to be noticed by the pilots. No appreciable control force was apparent to the pilots, which was considered somewhat undesirable. Minor modifications in the design of the ailerons, however, would probably correct this fault.

Wind-Tunnel Investigation of an N.A.C.A. 23012 Aerofoil with Two Arrangements of a Wide-Chord Slotted Flap. (T. A. Harris, N.A.C.A. Tech. Note No. 715, June, 1939.) (70/16 U.S.A.)

An investigation has been made in the N.A.C.A. 7- by 10-foot wind tunnel of a large-chord N.A.C.A. 23012 aerofoil with several arrangements of a 40 per cent. chord slotted flap to determine the section aerodynamic characteristics of the aerofoil as affected by slot shape, flap location, and flap deflection. The flap positions for maximum lift, the polars for arrangements considered favourable for take-off and climb, and the complete section aerodynamic characteristics for selected optimum arrangements were determined. A discussion is given of the relative merits of the various arrangements. A comparison is made of slotted flaps of different chords on the N.A.C.A. 23012 aerofoil.

The best 40 per cent. chord slotted flap is only slightly superior to the 25 per cent. chord slotted flap from considerations of maximum lift coefficient and low drag for take-off and initial climb.

Makhonine Variable Wing Area Aircraft. (Inter Avia, No. 662, 21/7/39, p. 4.) (70/17 France.)

The Makhonine aircraft with variable wing area has resumed its tests at Villaconblay. The first trial flights have proved satisfactory; they included full extension and retraction of the wing (maximum wing area 355 sq. ft. = 33 m.², minimum 194 sq. ft. = 18 m.², hydraulic operation) and were made with a gross weight of 7,940lb. (3,600 kg.). Maximum permissible gross weight 11,020lb. (5,000 kg.). The modified aircraft is equipped with a Gnome 14 No. engine of 1,000 c.v. and a landing gear that partly retracts into the wing leading edge.

The Effect of Incomplete Partition (Ribs) on the Force Distribution in Single Spar Wings. (F. Reinitzhuber, L.F.F., Vol. 16, No. 7, 20/7/39, pp. 349-354.) (70/18 Germany.)

The author shows how the force distribution due to incomplete partitions in single spar wing structure can be determined with the help of the stress field

diagram. The special case of the incomplete partition being subjected to torsion (torque reaction of wing engines) is considered more fully. It appears that the forces are distributed fairly evenly over the cross-section of the wing, the results depending, however, markedly on the stiffness of the partitions and more especially on that of the flanges at the rear of the torsion nose of the wing.

By means of a number of simple assumptions, it is possible to reduce the number of statically indetermined factors and then reduce the labour involved without material sacrifice of accuracy. If the two incomplete partitions carrying the wing engines are subjected to equal moments, it is possible, by means of a simple statically indetermined calculation, to obtain a useful approximation for the couple transmitted by the rear section of the wing.

Aerodynamics of Rotary Wing Systems Provided with Rotor Blade Incidence Control. (A. Pfluger, L.F.F., Vol. 16, No. 7, 20/7/39, pp. 355-361.) (70/19 Germany.)

The author considers the type of rotor construction in which the blades undergo a change of incidence by a twist about the longitudinal axis, the control being linked in such a way to the vertical blade motion that an upward motion of the blade is accompanied by a reduction in incidence. Such types of rotary wing aircraft have been experimented with by Bregnet and Hafner. The case considered is that of steady horizontal flight under conditions of auto-rotation, the method employed being based on that of Wheatley (N.A.C.A. Rep. 487) and Sissingh (L.F.F., Vol. 15, p. 290).

The results are applied to the special case of a machine weighing 900 kg. and resembling in its leading characteristics the Standard Autogiro Type C.30. It appears that the new incidence control shows no marked advantages over the standard Cierva control, and the amplitude of the vertical blade oscillations is not reduced. It must, however, not be forgotten that the comparison as carried out by the author applies to steady horizontal flight. A mechanical blade incidence control profoundly affects the characteristics of flight (take-off, climb, &c.) and the possible benefits accruing on this score may well outweigh the additional complications.

Empennage Design with Single and Multiple Vertical Surfaces. (L. E. Root, J. Aeron. Sci., Vol. 6, No. 9, July, 1939, pp. 353-360.) (70/20 U.S.A.)

Wind-tunnel tests on models with flaps up have been analysed to obtain surface and control efficiencies for empennages with single and double vertical surfaces. On the basis of these efficiencies and constant static longitudinal stability with (1) constant static directional stability, or (2) constant rudder control, required areas for the DC-4 are compared for empennages with single and double vertical surfaces. Hinge moments for single and double rudders giving constant control are compared; and methods of hinge moment reduction are briefly discussed. The variation of ground clearance is shown with single, double, or triple vertical surfaces. Aerodynamic effects of such design variations as horizontal surface tips, rudder cutouts, vertical location of double vertical surfaces, and horizontal surface dihedral angle are mentioned.

Choice of vertical surface type for a particular design is governed by the fact that (1) for constant rudder control, the single vertical surface gives a relatively high value of static directional stability; double vertical surfaces, a relatively low value; and triple vertical surfaces, an intermediate value with minimum over-all aeroplane height, and that (2) for constant rudder control, the total empennage area with single or double vertical surfaces is approximately equal for all aspect ratios; for constant static directional stability, the total area is less with the single vertical surface.

Towards a Rational Method of Tail Plane Design. (A. Silverstein, J. Aeron. Sci., Vol. 6. No. 9, July, 1939, pp. 361-369.) (70/21 U.S.A.)

The framework of a method for the design of tail planes is outlined, and both the extent of the existing knowledge available for its application and the important omissions are discussed. The method differs from the existing one most particularly in that the separate variables that influence the tail performance are given greater individual attention.

Experimental results are presented in some cases to show their relation with certain theories, or to illustrate the general nature of a phenomenon. It is concluded that further extensive research is required before a complete design solution of the tail plane problem can be made.

Hydrodynamic and Aerodynamic Tests of a Family of Models of Seaplane Floats with Varying Angles of Dead Rise, N.A.C.A. Models 57-A, 57-B and 57-C. (J. B. Parkinson, R. E. Olson and R. O. House, N.A.C.A. Tech. Note. No. 716, July, 1939.) (70/22 U.S.A.)

Three models of V-bottom floats for twin-float seaplanes (N.A.C.A. models 57-A, 57-B and 57-C) having angles of dead rise of 20°, 25° and 30°, respectively, were tested in the N.A.C.A. tank and in the N.A.C.A. 7- by 10-foot wind tunnel.

CONCLUSIONS.

1. The effect of angle of dead rise on water resistance in the range from 20° to 30° was negligible up to and including the hump speed. At planing speeds the resistance increased with an increase in the angle of dead rise, a trend similar to that obtained with planing plates.

2. The height and the amount of spray at the hump speed tended to decrease with an increase in the angle of dead rise from 20° to 30°.

3. The aerodynamic drag increased slightly with an increase in the angle of dead rise from 20° to 30°.

4. For floats having the usual cross-sectional shape and load coefficients for minimum allowable surplus buoyancy, the length-beam ratio of the forebody should be approximately 4.0, or larger, to run cleanly at low speeds on the water. Too short and bluff a forebody will result in excessive spray and resistance at speeds below the hump speed.

5. Spray strips were an effective means of reducing spray at the high loadings employed with seaplane floats, but they caused high aerodynamic drag.

The Effects of Partial Span Slotted Flaps on the Aerodynamic Characteristics of a Rectangular and a Tapered N.A.C.A. 23012 Wing. (R. O. House, N.A.C.A. Tech. Note No. 719, July, 1939.) (70/23 U.S.A.)

An investigation was made in the N.A.C.A. 7- by 10-foot wind tunnel to determine the aerodynamic characteristics of tapered and rectangular wings with partial-span slotted flaps. Two N.A.C.A. 23012 aerofoils equipped with centre-section and tip-section flaps were tested.

The results showed that the changes in lift and drag due to changes in flap span for both rectangular and tapered wings having partial-span slotted flaps were similar to those for corresponding wings having partial-span split or plain flaps. For the two wings tested, higher values of maximum lift were obtained with centre-section slotted flaps than with tip-section slotted flaps of the same size. The highest values of lift-drag ratio at maximum lift for the rectangular wing were obtained with centre-section flaps and, for the tapered wing, with tip-section flaps. Centre-section flaps on the tapered wing gave higher values of drag at maximum lift than tip-section flaps; no great difference in drag at maximum lift was apparent for either centre-section or tip-section slotted flaps on the rectangular wing.

It should be borne in mind that the point along the span at which the stall begins may have an appreciable effect on the value of the maximum lift obtained in flight. If the tips stall first any further increase in angle of attack is limited, although it may be several degrees below the angle at which maximum lift is obtained in a wind tunnel. Consequently some of the values of the maximum lift coefficient given for the tapered wing and for the rectangular wing with centre-section flaps may be somewhat higher than those attainable in flight.

Axial Flow Superchargers. (A. Betz, Yearbook of German Aeronautical Research 1938, Vol. 2, pp. 183-186) (in course of translation.) (70/24 Germany.)

Axial type blowers have the advantage of small diameter and high efficiency. Their disadvantage is the constructional length, five impellers being required for a compression ratio of 2/1.

It is not possible to cut down the space occupied by the intermediate stationary guide vanes unless contrary rotating impellers are employed. Although such a type has proved successful on test employing two impellers, it is feared that the mechanical difficulties of extending this method drive to three or more impellers will rule out this construction for aircraft use.

The author has carried out a series of experiments with the object of improving the compression ratio per stage and in this way cutting down the number of impellers required. By very accurate manufacture of the blades and adopting special shapes it has been possible to improve the pressure ratio per stage by 20 per cent.

Further improvement along these lines appears very difficult, apparently due to complicated effects in the boundary layer under conditions of rotary air flow.

Another line of approach is to work deliberately in the supersonic region. Theory indicates that by this means a considerable increase in compression ratio should be possible. Experiments on these lines are still in a very preliminary state and the author is not in a position to report any definite results.

Aircraft Supercharger with Radial or Backward Curved Blades. (C. Pfleiderer, Yearbook of German Aeronautical Research, 1938, Vol. 2, pp. 187-195.) 70/25 Germany.)

As is well known, for a given peripheral speed, the theoretical compression head increases as the blade shape is changed from backward to forward curvature. On the other hand both efficiency and stability of operation suffer, and harmful effects due to attainment of supersonic air speeds are likely to arise.

In the case of the aircraft supercharger, the urgent requirements of small size and weight, however, require such high speeds of operation that the ultimate strength of the blade becomes the decisive factor, *i.e.*, the exit angle at the blade must be $\geq 90°$.

The author shows how the stability of operation can be improved by proper installation (*i.e.*, small pipe capacity on either side of blower) and how a properly designed vaneless diffuser overcomes supersonic difficulties.

Compared with the advantage of compactness and low weight, the drop in compression efficiency is not serious and it is thought that the radial vane will hold the field for single stage aircraft superchargers for some time to come.

Critical Oscillations in the Suction and Exhaust Pipes of Straight-Type Engines. (O. Lutz, L.F.F., Vol. 16, No. 3, 20/3/39, pp. 139-147) (Eng. Absts., Vol. 2, No. 6, Sect. 2, June, 1939, p. 71.) (70/26 Germany.)

The author describes a method of calculating the critical frequencies in lines of piping in which oscillations are set up at more than one point. He cites an earlier publication (Bulletin No. 3 of the Laboratory for Internal-Combustion Engines of Stuttgart Technical University, 1934), in which he discussed oscillations set

up at a single point of a line piping. He recapitulates briefly the procedure then adopted which was based upon the differential equations for the propagation of sound, and demonstrates that the oscillation phenomena resulting from the generation of waves at several points can be treated as oscillations in a number of open pipes, the resultant oscillation being obtained by superposition. He gives examples of the generation of oscillations by fluctuations of the flow-velocity at various points of a pipe-line, and investigates the influence of variations of the cross-section and of throttling. More complex systems of mains and branch lines will be discussed later.

Development Problems on Rotating Boiler-Turbines. (F. Huttner, Z.V.D.I., Vol. 83, No. 14, 8/4/39, pp. 397-404) (Eng. Absts., Vol. 2, No. 6, Sect. 2, June, 1939, p. 70.) (70/27 Germany.)

The author considers that the rotating steam-generator is a decisive step in the mechanical utilisation of heat, and that its association with a turbine opens up wide possibilities. He discusses the developments during the past 15 years and the lessons to be learned from them and asserts that the two main factors which afford scope for advancement are improved radiation from the furnace and improved conditions for the passage of conducted heat. He discusses the principle upon which the system is based, describes test-machines, and states that, despite a small depth of heating surface, the boiler efficiency was 80 per cent. at an exhaust-gas temperature of 150-250°C., whilst higher efficiency would have been possible with pre-heated air. Although the tests were on a small scale, he considers that they offer encouragement for development to larger powers. He discusses in detail the suitability for working with saturated steam, the thermal efficiency of the system, the improvement of the heating surface, and arrangements for gas-firing and oil-firing; he considers that the time is ripe for wider developments, but that these will entail a study of the problem of condensation.

The Influence of Injection-Timing on the Delay-Period in a Compression-Ignition Engine. (J. Riffkin, Engineering, Vol. 147, No. 3826, 12/5/39, pp. 552-553) (Eng. Absts., Vol. 2, No. 6, Sect. 2, June, 1939, p. 70.) (70/28 Great Britain.)

Tests were made on a single-cylinder four-stroke-cycle open-combustion-chamber compression-ignition engine provided with a special injection system to enable the injection-timing to be varied over a wide range while the engine was in operation. Three different fuel oils were supplied in turn, and engine performance data, including measurements of the delay period, were recorded for each change of injection-timing. The author concludes that the timing of injection influenced the value of the delay-period, and that the prevailing temperature in the combustion chamber at the instant of fuel-injection was probably the chief controlling factor.

Hydraulic Starter for Oil and Petrol Engines. (The Oil Engine, Vol. 6, No. 72, April, 1939, p. 366) (Eng. Absts., Vol. 2, No. 5, Section 3, June, 1939, p. 109.) (70/29 Great Britain.)

The Berger starter, made by a Paris firm holding the manufacturing rights for France and the U.K., is primarily intended for aircraft engines. The smallest model weighs 7.2lb., and will deal with engines of from 60 to 200 b.h.p., whilst the larger model weighing 15.9lb. is suitable for engines up to 1,600 b.h.p. There are two intermediate sizes. The power medium employed is hydraulic; oil is supplied by a small-bore pump driven by an electric motor, by the engine itself, or by hand. The pump feeds an accumulator, which contains air at high pressure; this air provides a form of spring loading on the oil, which operates on the starter pistons at a pressure up to 3,550lb./in.^{2}. The body of the device contains two pistons with helical-toothed racks actuating the pinion which drives

the engine crankshaft through dog clutches. The pistons are returned, after each working stroke, by springs to the outer ends of cylinders.

Improvements in Aeroplane Engines. (R. Combes, Bull. Soc. Enc. Industr., Nat. Paris, April, 1939, pp. 221-243) (Eng. Absts., Vol. 2, No. 6, Sect. 2, June, 1939, p. 70.) (70/30 France.)

The author reviews briefly the progress made in the performances of aeroplane engines, and examines, from the experimenter's point of view, the means whereby the present high standard has been attained and the directions in which further progress may be expected in the near future. He considers that recent progress has been due chiefly to three main causes, namely: (1) conditions of reception representing more closely the needs of actual service; (2) greater attention to efficient cooling; (3) improvements in carburants. The provision of short time supercharge tests permitted increased power for taking off to be obtained by increasing the admission pressure, and the utilisation to the greatest advantage of richer mixtures and higher speeds of rotation; it also led to reduced fuel consumption in cruising by reducing the maximum power at which such low specific consumptions were permissible. By permitting the use of weaker mixtures without risk of knocking, improvements in cooling—and also improvements in carburants—contributed not only to reduction of fuel consumption in cruising, but also to improved characteristics in climbing. The author considers that further improvement in the performance of existing types of engines may be achieved by reduction of losses of head, increased efficiency of compressors, and better adaption of the compressor to the engine, the ideal being a compressor working at optimum efficiency for all rates of air-supply required by the engine. Recent experiments bearing on the problem are described.

Gas Turbine Developments. (S. A. Tucker, Power, June, 1939, pp. 58-61. Metropolitan Vickers Technical News Bulletin, No. 666, 23/6/39, p. 6.) (70/31 U.S.A.)

This article gives a brief account of the development of the gas turbine in the U.S.A. during the past few years. Descriptions of 11 by-product gas turbine sets at present in course of production by Messrs. Brown-Boveri and Allis-Chalmers are included, and, also, details of a number of such sets in operation for several years past. The advantages and limitations of such turbines are outlined.

Illustrated with one photograph and five diagrams.

Atomisation of Oil by Small Pressure-Atomising Nozzles (Domestic Oil Burners). (E. B. Glendenning, A. R. Black, L. H. Ventres and W. A. Sullivan, Trans. A.S.M.E., Vol. 61, No. 5, July, 1939, pp. 373-381.) (70/32 U.S.A.)

1. One of the most important characteristics of an oil from the standpoint of atomisation is viscosity. Viscosity influences nozzle capacity, angle of spray, degree of atomisation, character of flame, and efficiency of combustion. Since the viscosity of the oil at atomising temperature is of first importance, the viscosity-temperature characteristics of an oil must be taken into consideration.

2. Nozzle design has an important bearing on the character of the spray and the sensitivity of the nozzle to variations in the atomising pressure and the viscosity of the oil. This calls for careful balancing of the sizes of the slots, vortex chamber and orifice to produce the desired tangential and axial velocities at the exit of the nozzle.

3. Of particular importance for efficient combustion is the placement of the combustion air as it conforms with the shape and nature of the oil spray.

4. Efficiency of combustion and economy of heating with oil in domestic pressure-atomising burners depends largely upon the selection of a nozzle having

the proper atomising characteristics, the correct aerodynamic design of the burner, and the use of an oil of correct and uniform viscosity.

Combustion Gas Turbine. (A. Meyer, Machinery Market, 21/7/39, pp. 21-22. Metropolitan Vickers Technical News Bulletin, No. 671, 28/7/39, p. 3.) (70/33 Great Britain.)

In this first of a series of articles, the author traces the history of the turbine, and the problems that confronted the early inventors, such as cooling and simplification of design. The first gas turbine to be designed was Stolze's hot air turbine in 1872, although its trials did not take place until 1900-1904. A description of the mechanism of turbines of this type is given. Due to the low efficiency of these early types, Holzworth developed the explosion type, and the article proceeds to describe its method of working. The history of this type of turbine is traced down to the present day and the part played by Brown-Boveri in its development.

Illustrated with three diagrams and two graphs.

Gland Seals. (K. Trutnovsky, Z.V.D.I., 22/7/39, pp. 857-858. Metropolitan Vickers Technical News Bulletin, No. 671, 28/7/39, p. 9.) (70/34 Germany.)

It is pointed out that in machines in which metallic surfaces having relative motion separate spaces subject to varying pressures and high temperatures, *e.g.*, cylinders of thermal prime movers, great difficulty is often experienced in achieving satisfactory lubrication and wear of the sealing parts. In these cases the use of contract-free gland seals is advantageous. In particular the author considers the fundamental differences in the behaviour of the smooth gap and the labyrinth gland, the influence of the modification of characteristic dimensions on the inertia of the labyrinth gland and makes a comparison of gland seals.

Illustrated with eight diagrams.

Poppet Valve Dynamics. (E. H. Olmstead and E. S. Taylor, J. Aeron. Sci., Vol. 6, No. 9, July, 1939, pp. 370-375.) (70/35 U.S.A.)

Measurements of the motion of a pushrod-operated poppet valve at normal operating speed showed considerable deviation from the motion at low speed. Jumping was observed at a speed very much lower than the speed which would be predicted by the usual analysis. The observed discrepancy is attributed to flexibility in the operating mechanism. A mathematical analysis is presented which takes account of flexibility and gives a reasonable check on the observed motion. The effect of speed, valve spring pressure and cam form was investigated by means of a mechanical model. Special cam forms for eliminating jumping at a single speed are suggested.

The Influence of Directed Air Flow on Combustion in a Spark-Ignition Engine. (A. M. Rothrock and R. C. Spencer, N.A.C.A. Tech. Report No. 657, 1939.) (70/36 U.S.A.)

The N.A.C.A. combustion apparatus consists of a 5×7 single-cylinder test engine with a large glass window in the head to permit the combustion to be studied photographically. The engine is motored at the required speed and is then fired once by injecting and igniting a single charge of fuel. The air movement in the cylinder was regulated by using shrouded inlet valves and by fairing the inlet passage. Rates of combustion were determined at different inlet-air velocities with the engine speed maintained constant and at different engine speeds with the inlet-air velocity maintained approximately constant.

The rate of combustion increased when the engine speed was doubled without changing the inlet-air velocity; the observed increase was about the same as

the increase in the rate of combustion obtained by doubling the inlet-air velocity without changing the engine speed.

Certain types of directed air movement gave great improvement in the reproducibility of the explosions from cycle to cycle, provided that other variables were controlled.

Directing the inlet air past the injection valve during injection increased the rate of burning.

Liquid Ammonia as a Motor Fuel. (La Science et la Vie, No. 265, July, 1939, pp. 51-52.) (70/37 France.)

The liquid ammonia is vaporised and then passes over a catalyst which causes between 5-10 per cent. of the vapour to be decomposed into hydrogen. This hydrogen acts as a primer to the combustion.

According to the Phillips Petroleum Corporation, a 6 per cent. addition of liquid ammonia to ordinary petrol raises the permissible compression ratio appreciably.

Moreover the lead susceptibility of the petrol is markedly increased in the presence of ammonia.

The Hydrodynamic Theory of Detonation. (H. Langweiler, Zeit. Technische Physik, Vol. 19, No. 9, 1938, pp. 271-283.) (Available as Translation T.M.899.) (70/38 Germany.)

The author derives equations containing only directly measurable constants for the quantities involved in the hydrodynamic theory of detonation. The stable detonation speed, D, is revealed as having the lowest possible value in the case of positive material velocity, by finding the minimum of the Du curve (u denotes the speed of the gases of combustion). A study of the conditions of energy and the disclosure of a rarefaction front travelling at a lower speed behind the detonation front; its velocity is computed. The latent energy of the explosive passes into the steadily growing detonation zone—the region between the detonation front and the rarefaction front. The conclusions lead to a new definition of the concept of shattering power. The calculations are based on the behaviour of trinitrotoluene.

The Knocking Characteristics of Fuels in Relation to Maximum Permissible Performance of Aircraft Engines. (A. M. Rothrock and A. E. Bierman, N.A.C.A. Tech. Report No. 655, 1939.) (70/39 U.S.A.)

The results presented in this report show that, by a determination of the knocking characteristics of a fuel in an engine as a function of the highest permissible inlet-air density at any inlet-air temperature, data obtained at one compression ratio or at one inlet-air pressure are applicable to a series of inlet-air pressures and compression ratios at the different inlet-air temperatures tested.

Analysis of the more important engine factors affecting knock leads to the conclusion that the most important independent variables in any one engine are the inlet-mixture density and temperature and the mixture ratio.

The data show that preignition must be treated separately from knock if the fuels are to be adequately rated in the engine. In the case of knock, the maximum permissible performance increases with speed for a constant spark advance; whereas, with preignition, the indication is that the maximum permissible performance decreases with engine speed.

The Constitution and Application of Thermo-Electric Instruments. (L. B. Lambert, Eng. and Boiler-House Review, July, 1938, pp. 38-42. Metropolitan Vickers Tech. News Bulletin, No. 669, 14/7/39, p. 1.) (70/40 Great Britain.)

The article deals with the large range of pyrometric instruments now available and their application in the boiler house, turbine room, and other fields.

The author describes the principles of the thermo-electric couple and the various difficulties encountered in its use. He then deals with methods by which these difficulties are overcome. He also mentions the most suitable metals and alloys used in these instruments and the reasons for their suitability.

Illustrated with three photographs and five diagrams.

The Vectorscope. (G. Dashefsky, Trans. A.S.M.E., Vol. 61, No. 5, July, 1939, pp. 403-414.) (70/41 U.S.A.)

This paper describes a new instrument capable of rapidly summing up a number of vectors. The machine consists of a disk, mounted in gimbals in the manner of a nautical compass, on which are placed weights representing the vectors to be added. A spot of light on the screen indicates directly the resultant vector and its direction, as well as its horizontal and vertical components.

The mathematical principle is developed and the instrument is shown to be suitable for studying crankshaft arrangements with respect to unbalanced moments and torsional vibration. The suitability of any firing order for any crankshaft configuration may be ascertained simply and quickly.

It is shown that the instrument is inherently adapted to making harmonic analyses of periodic functions and the theory of this application is discussed. Results by this method of analysis compare favourably with other methods.

X-Ray Determination of the Notch-Factor of Notched Rods. (H. Krachter, Z. Metallk., April, 1939, pp. 114-115. Eng. Absts., Vol. 2, No. 6, Sect. 1, June, 1939, p. 50.) (70/42 Germany.)

The author observes that a knowledge of the increase of stress across the cross-section, especially of notched rods, is of considerable practical importance in structural engineering. The most important factor is the form or notch-factor, α_k, which is the ratio of the maximum stress σ_{max}, to the nominal stress, σ_n. In notched rods, this can be obtained only by approximate calculation or by the use of models. The author has applied X-rays to determine this factor by a difference method. First, by means of vertical radiation, the sum of the longitudinal and circumferential stresses $(\sigma_l + \sigma_u)$ was measured by the method of Wever and Moller, and then the circumferential stress, σ_u, alone was measured by oblique radiation at 45° by Glocker's method; then $\sigma_k = \frac{(\sigma_l + \sigma_u) - \sigma_u}{\sigma_n}$. The notch-factor was plotted against the notch-depth, and the resulting curve indicated that, as the notch-depth increases, the notch-factor increases up to a critical value of the notch-depth, and thereafter decreases.

Recent Welding Developments in the U.S.A. R. M. Gooderham, Welding Ind., June, 1939, pp. 164-170. Metropolitan Vickers Technical News Bulletin No. 666, 23/6/39, p. 5.) (70/43 U.S.A.)

The following article presents a general survey of the progress of welding in the United States during the past year. Reasons for the greatly increased use of welding are given. Various fields of application are detailed, such as the motor car industry, shipbuilding, structural welding and machine fabrication and indications given of future developments in these industries. Investigations into weld strengths by various methods are reviewed, as also the establishing of proper welding technique, symbols, procedure and preparation of materials, etc.

Illustrated with nine photographs.

New Resistance Material "Novokonstant." (E.T.Z., 15/6/39, pp. 729-730. Metropolitan Vickers Technical News Bulletin No. 666, 23/6/39, p. 8.) (70/44 Germany.)

Abstract from an article in Phys. Zeit. (1939), p. 357, describing tests carried out in the National Physical and Technical Institute on a new resistance material

called " Novokonstant." This is a copper-manganese alloy containing 82.5 per cent. Cu, 4 per cent. Al, 1.5 per cent. Fe and 12 per cent. Mn. The electrical behaviour of the material as a whole indicates its suitability for precision resistances. Details are given among other things of the relation between the electrical resistance of " Novokonstant " (and its temperature coefficient) and the temperature, the relation between the resistance temperature curve and the ageing curve, etc.

Illustrated with two diagrams and one photograph.

The Column Strength of Two Extruded Aluminium-Alloy H-Sections. (W. R. Osgood and M. Holt, N.A.C.A. Tech Report No. 656, 1939.) (70/45 U.S.A.)

Extruded aluminium-alloy members of various cross-sections are used in aircraft as compression members either singly or as stiffeners for aluminium-alloy sheet. In order to design such members, it is necessary to know their column strength, or, in the case of stiffeners, the value of the double modulus, which is best obtained for practical purposes from column tests.

Column tests made on two extruded H-sections are described, and column formulæ and formulæ for the ratio of the double modulus to Young's modulus, based on the tests, are given.

Experiments with D.V.L. Bearing Testing Machine on Lead Bronze Bearings Cast on Steel Shells. (G Fischer, L.F.F., Vol. 16, No. 7, 20/7/39, pp. 370-383.) (70/46 Germany.)

Although research with light alloy bearings has been very active, such materials are not yet considered suitable for the highly stressed aero-engine bearings. As a result, lead bronze bearings are still standard practice although their manufacture is complicated. The normal casting procedure has been to immerse the steel shell for a considerable time in the molten alloy, after which it is rapidly quenched. This ensures good adhesion, but is apt to make the lead distribution throughout the mass non uniform (gravity diffusion in the bath). In this connection it may be advantageous to produce the melt in an electric furnace of the high frequency coreless induction type. Another suggested line of development consists in using separate castings for the bearing and supporting shell, the junction being subsequently produced by means of a third alloy of high diffusion.

The author describes tests on 12 lead bronze bearings supplied by five firms. The load capacity of the bearings was determined as well as their behaviour on duration runs both with steady and alternating load. The results show the importance of uniform good lead distribution and the harmful effect of impurities (chiefly iron). In a number of cases the early formation of cracks has been traced to stresses introduced during manufacture.

Radiography in Iron and Steel Founding. (F. W. Rowe, Foundry Trade Journal 20/7/39, pp. 43-47. Metropolitan Vickers Technical News Bulletin, No. 671, 28/7/39, p. 4.) (70/47 Great Britain.)

Particulars in the manipulation of both X-ray and gamma-ray apparatus are given and the relative merits of both types are discussed. The cost of film, developing, film holders, etc., does not differ greatly. Gamma-ray practice offers marked advantages in the way of operating expense, as the operator may go about other work during exposure. Several examples of work encountered in the use of radiography are given.

Illustrated with 16 radiographs and one diagram.

The Lower Limiting Crystallite Size and Internal Strains in Some Cold Worked Metals. (W. A. Wood, Proc. Roy. Soc. Series A, Vol. 172, No. 949, 3/8/29, pp. 231-241.) (70/48 Great Britain.)

An X-Ray examination has been made of the changes in crystalline structure during the progressive cold working of pure Cu, Ag, Ni, Al, Mo and Fe. It is shown that the grains are dispersed into a fundamental unit (crystallite) characterised by a lower limiting size ranging from 10^{-4} cm. for Al to 0.7×10^{-5} cm. for Cu. This size is deduced from the broadening of appropriate diffraction lines. It is further shown, in the general case of copper, that on continued cold working the diffraction lines broaden to a maximum and then diminish in width to a definite value, the two processes alternating on further working. At the same time, the lattice dimensions of the crystallites change, having an expanded value when the line is most diffuse and a contracted value when the line breadth decreases. These changes are measured and indicate that the condition of the cold worked metal is marked by two extremes, (i) a comparatively stable state with a contracted lattice and minimum line broadening giving the lower limiting crystallite size, and (ii) a less stable state characterised by an expanded lattice and an abnormally diffuse line breadth which represents the extent and nature of the distortion transmitted to and retained by the metallic lattice during continued deformation.

The Friction of Clean Metals and the Influence of Adsorbed Gases. The Temperature Coefficient of Friction. F. P. Bowden and T. P. Hughes, Proc. Roy. Soc., Series A, Vol. 172, No. 949, 3/8/39, pp. 263-279.) (70/49 Great Britain.)

A method is described for measuring the kinetic friction between metal surfaces which have been freed from the oxide and surface films which are normally present. The removal of the films has a profound effect and the kinetic friction between the outgassed metals may be 20 times greater than that observed for the same metals cleaned in air.

The addition of a trace of oxygen to the clean metal causes an immediate reduction in the friction. Adsorbed hydrogen and nitrogen have little or no effect. Although the friction is reduced by a single film it is clear that polymolecular layers are necessary before a substance can act as an effective boundary lubricant for moving surfaces.

The temperature coefficient of friction between clean metals was determined over a wide temperature range. Most of the metals investigated show a small but regular decrease in the kinetic friction as the temperature rises. If the temperature causes excessive softening of the metal the friction may rise to a high value.

The Mechanism of Sliding on Ice and Snow. (F. P. Bowden and T. P. Hughes, Proc. Roy. Soc., Series A, Vol. 172, No. 949, 3/8/39, pp. 280-297.) (70/50 Great Britain.)

Experimental studies of the friction on ice surfaces have shown that the low frictions observed at temperatures near the melting point were due to lubrication by a thin water film at the points of contact between the sliding surfaces. The coefficient of kinetic friction was found to be independent of the load, apparent area of contact, and speed of sliding over a certain range. When the temperature of the ice was decreased the friction rose markedly as the water film became more difficult to form. Using ski of various materials, it was observed that the friction depended very largely on the thermal conductivity of the ski. This result suggested that frictional heating played a large part in melting a water film during sliding; it had been previously considered that pressure melting was alone responsible for the formation of this water film.

Experiments with miniature and real ski on snow surfaces showed that the same general laws were obeyed as on ice surfaces. The higher frictions obtained on snow were attributed to the extra work done in displacing and compressing the snow crystals.

Stress-Optical Investigation on a Square Plate Fitted with a Central Square Hole. (A. Schreyer, Forschung, Vol. 10, No. 4, July-August, 1939, pp. 157-164.) 70/51 Germany.)

The experiments are in excellent agreement with previous theoretical investigation of the author. This applies especially to the complicated phenomena arising at the internal corners.

It is confirmed that in the case of multi-connected regions where the forces acting on the inner edges are in equilibrium the resulting stress distribution is independent of the lateral contraction.

Stress distribution obtained by optical means can therefore be applied directly to other materials.

It appears that a good approximation to the stress distribution at the edge (position of zero and maximum stress) can be obtained from a study of the isochromatic lines alone without reference to the isoclinics.

This is of importance in the case of complicated multi-connected regions which are not amenable to mathematical treatment.

The Effect of Continuous Weathering on Light Metal Alloys Used in Aircraft. (W. Mutchler, N.A.C.A. Report, No. 663, 1939.) 70/52 U.S.A.)

An investigation of the corrosion of light metal alloys used in aircraft was begun at the National Bureau of Standards in 1925, and has for its purpose the study of the causes of corrosion in aluminium-rich and magnesium-rich alloys together with the development of methods for its prevention.

The results, obtained in an extensive series of laboratory and weather-exposure tests, reveal the relative durability of a number of commercially available materials and the extent to which the application of various surface coatings of oxide alone and with paint coatings afforded additional protection. The paper may be considered as a supplement to N.A.C.A. Report No. 490.

A Method of Estimating the Critical Buckling Load of Structural Members. (E. E. Lundquist, N.A.C.A. Tech. Note No. 717, July, 1939.) (70/53 U.S.A.)

The relation between load on the structure and rotation of a joint can be used to estimate the lowest critical load, after the equation for neutral stability has been tested for three assumed critical loads, each of which is less than the lowest critical load.

The solutions of six problems are included to illustrate the method. Four of these problems are concerned with members that lie in the elastic (long-column) range. The remainder deal with members in the short column range.

When all the members are in compression, the calculation over-estimates the critical load. The region of good agreement cannot be stated generally. Transition from over to under-estimation is likely to occur when the size, axial load or number of tension members, is small relative to the compression members.

The method of estimating the critical load should always be regarded as a tool to aid in finding the lowest load that satisfies the equations for neutral stability. This lowest load is the calculated critical load for the problem.

Resistance of Transparent Plastics to Impact. (B. M. Axilrod and G. M. Kline, N.A.C.A. Tech. Note No. 718, July, 1939.) (70/54 U.S.A.)

The problem of developing a windshield for aircraft which will withstand the effect of bird impact during flight is difficult. If a 4lb. bird is involved, an

impact energy of the order of 10,000 foot lbs. may have to be dissipated (relative speed 400 feet/sec.). The present report gives the results of a comparative study of the impact strength of various types of transparent plastics with particular reference to their ability to withstand impacts with relatively soft bodies, such as a shot filled sponge rubber ball. A 4lb. ball travelling at 400 feet/sec. could not be stopped by plastic materials up to ½in. thick or glass products up to 1.2in. thick.

Four ¼in. sheets of cellulose acetate bolted together and a sheet of tempered glass 1.2in. were also broken when struck by a 3in. ball travelling at 300 feet/sec. (normal impact), but withstood the impact when inclined at 45°.

Improvements and Experience in Radio Soundings. (H. Diamond, W. S. Hinman, A. H. Mears and C. Harmantas, J. Aeron. Sci., Vol. 6, No. 9, July, 1939, pp. 379-383.) (70/55 U.S.A.)

Further improvements of the radio sonde developed at the National Bureau of Standards for the U.S. Navy Department are described. The improvements were directed to facilitate the mass production of the instrument while retaining its accuracy and simplicity. An analysis, based on data of the U.S. Weather Bureau, of the performance of the improved instrument in routine use at six Weather Bureau and one Navy Department aerological stations is presented. A quantitative evaluation of the accuracy of the radio sonde observations is included. The radio sonde system has provided a continuous sequence of upper-air observations to much greater heights and with greater regularity and reliability than the aeroplane method of sounding hitherto employed. Plans of the Weather Bureau and the Navy Department call for routine use of the instrument described at about 35 aerological stations, during the fiscal year 1940.

Graphical Determination of the Coefficient of Heat Transfer for Banks of Tubes. (J. Böhm, Wärme, 1/7/39, pp. 425-431. Metropolitan Vickers Tech. News Bull., No. 669, 14/7/39, p. 8.) (70/56 Germany.)

After reviewing the present state of knowledge of the transfer of heat from gases to banks of tubes, the author develops a graphical method which, with the aid of a nomogram, enables the coefficient of heat transfer to be rapidly and reliably determined. He gives examples which show how the influence of modifications can be clearly observed with the help of the nomogram.

Illustrated with 13 diagrams.

Temperature Distribution in Circular Discs. (E. Beck, Forschung, July-August, 1939, pp. 165-169. Metropolitan Vickers Technical News Bulletin, No. 671, 28/7/39, p. 8.) (70/57 Germany.)

For a circular disc of equal thickness the author develops the differential equation for heat conduction, whose solution reproduces the temperature field in the disc. The theory is then extended to discs of arbitrary cross-section, and the method is also applied to a turbine disc. It is found that, in consequence of the dissipation of heat at the disc, the temperature declines considerably from the foot of the blade to the middle of the disc. Corresponding temperature stresses are set up, which may in no case be disregarded during the design of the disc. The importance of a knowledge of the temperature distribution is stressed especially in those cases in which artificial cooling of the turbine rotor at the disc is used.

Illustrated with three diagrams.

The Production of Ultra-High-Frequency Oscillations by Means of Diodes. (F. B. Llewellyn, A. E. Bowen, Bell Telephones Pubs., No. B.1143, 1939, pp. 1-12.) (70/58 U.S.A.)

The general problem of obtaining oscillations by the use of diodes with critical electron transit time is outlined. Some of the properties of a 10 cm. oscillator

tested experimentally are included. Extraneous losses were reduced when the oscillator was enclosed within a wave guide.

Narrow Band Transmission System for Animated Line Images. (A. M. Skellett, Bell Telephone Pubs., No. B.1136, 1939, pp. 1-7.) (70/59 U.S.A.)

A method of transmission and reproduction of line images is described which utilizes a cathode-ray tube for reproduction, the spot of which is made to trace out the line image 20 or more times a second. In an experimental test a drawing of a woman's head was reproduced with an equivalent total band width of approximately 2,600 cycles. This was made up of two bands, each 1,300 cycles wide for the potentials to the two sets of cathode-ray deflector plates. Analysis of a more complex image, such as that of an animated cartoon shows that such material could be transmitted and reproduced by this method within a total band width of 10,000 cycles.

Means are described for transcribing from drawing or animated cartoon film into recordings (similar to sound recordings) from which the potentials for transmission and subsequent operation of the cathode-ray tube may be obtained.

Radio Telephone System for Harbour and Coastal Services. (C. N. Anderson and H. M. Pruden, Bell Telephone Publications B.1147, pp. 1-22.) (70/60 U.S.A.)

Radio telephone service with harbour and coastal vessels is now being given through coastal stations in the vicinities of seven large harbours on the Atlantic and Pacific coasts with additional stations planned. The system is designed to be as simple as possible from both the technical and operating standpoints on both ship and shore.

Recent developments in the shore-station design eliminates all manipulations of the controls by the technical operator. This is made possible principally because of crystal-controlled frequencies on shore and ship, a " vogad " which keeps the transmitting volume of the above subscriber constant, and a " codan " incorporated in the shore radio receiver which will operate on signal carrier but is highly discriminatory against noise.

A signalling system permits the traffic operator to call in an individual boat by dialling the assigned code which rings a bell on the particular boat called. The ship calls the shore station by turning on the transmitter. The radio signal operates the codan in the shore receiver, which, in turn, lights a signal lamp in the traffic switchboard.

Gradually the system has been taking on more and more the aspects of wire telephone systems.

LIST OF SELECTED TRANSLATIONS.

NOTE:—Applications for the supply of copies of translations mentioned below should be addressed to the Under Secretary of State (R.T.P.), Air Ministry, Berkeley Square House, W.1, and will be supplied, free of all charge, as far as availability of stocks permit. Suggestions concerning new translations will be considered in relation to general interest and facilities available.

Lists of selected translations have appeared in this publication since September, 1938.

THEORY OF WARFARE.

TRANSLATION NUMBER AND AUTHOR.	TITLE AND JOURNAL.
703 Sweeny	*The Aerial War in Spain Viewed from the Republican Side.* (L'Aérophile, Vol. 43, No. 3, March, 1938, pp. 55-57.)
926 Fucini, H.	*The Armament of the Single-Seat Fighter, with Special Reference to Experience in Spain.* (Riv. Aeron., Vol. 14, No. 12, December, 1938, pp. 476-88.)
927 Wehage	*New Italian Investigation on the Calculation of the Path of a Projectile by the Successive Arc Method.* (Beitrage zur Ballistik und Technische Physik, 1938, pp. 12-23.)
928 Knobloch, H. ...	*Approximate Formulæ for the Ballistics of Oscillating Bombs.* (Z.G.S.S., Vol. 33, No. 12, December, 1938, pp. 346-8.)
935 Knobloch, H. ...	*Fundamentals of Bomb Trajectories.* (Beitrage zur Ballistik und Technischen Physik, 1938, pp. 23-44—H. Schardin.)

AIRCRAFT.

929 Hohenemser, K. ...	*The Dynamic Stability of a Helicopter Fitted with Hinged Rotor Blades.* (Ing.-Arch., Vol. 9, No. 6, December, 1938, pp. 419-28.)
930 Haus, M.	*Aerodynamic Principles of Automatic Stabilisers.* (German Yearbook of Research, 1938, Supplement (Lilienthal Papers), pp. 273-306.)
934 Schapitz, E. ... ... Feller, H. ... ... Köller, H.	*Experimental and Mathematical Investigation on a Stressed-Skin Model Wing Subjected to Bending.* (Luftfahrtforschung, Vol. 15, No. 12, 10/12/38, pp. 563-76.)
936 Hübner, W.	*Some Results of Extended Tests on the Flying Qualities of the Focke-Wulf F.19A Aircraft "Ente."* (D.V.L. Yearbook, 1933, pp. iv 18-28.)

Aerodynamics and Hydrodynamics.

Translation number and author.			Title and journal.
931	Von Borbély	... ...	*On a Limiting Case of Three-Dimensional Unsteady Flow around a Wing.* (Z.A.M.M., Vol. 18, No. 6, December, 1938, pp. 319-342.)
932	Mangler, W.	...	*Calculation of a Wing Profile having a Specified Pressure Distribution.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 1, pp. 46-53.)
937	Walz, A.	... ...	*Conversion of Measured Pressure Distribution to any Angle of Incidence.* (L.F.F., Vol. 16, No. 3, 20/3/39, pp. 121-8.)

Wireless.

99.	Eisner, F.		*Increase in the Effective Height of Trailing Aerials.* (L.F.F., Vol. 8, No. 6, 3/3/31, D.V.L. Report, No. 207.)
	Sudeck, G.		
	Schroer, R.		
	Zinke, O.		
933	Gundlach, F. W.	...	*The Modulation of High-Frequency Transmitters by Limitation of Amplitude.* (Hochfrequenzt. u. Elektroakustik, Vol. 53, No. 1, January, 1939, pp. 10-18.)

ABSTRACTS OF PATENT SPECIFICATIONS.

(Specially abstracted for the Journal by W. O. Manning, F.R.Ae.S.)

Abstracts of Patent Specifications received by the Society are published in the Journal. It should be noted that these abstracts are specially compiled by Mr. W. O. Manning, F.R.Ae.S., for the Journal and are only of those actually received and subsequently bound in volume form for reference in the library. These volumes extend from the earliest aeronautical patents to date, and form a unique collection of the efforts which have been made to conquer the air.

The Council accept no responsibility whatever for the accuracy of the abstracts and in any case of doubt the full patent can be consulted when necessary in the Library of the Society.

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AERODYNAMICS.

501,879. *Improvements in Aircraft.* Ronand, R. L. M. F., 3, Villa Robert Lindet, Paris, Seine, France. Convention dates (France), May 24th, 1937; May 9th, 1938.

Each wing of an aeroplane is pivoted about an axis which converges rearwardly, so that, as the wing rotates, owing to the action of the aerodynamic overloads to which it is subjected, a variation of the incidence is obtained in a direction which limits such overloads. The maintenance of the wing in the position of equilibrium is ensured by elastic means which may be damped.

504,360. *Improvement in Aeroplanes.* Flight Lieut. H. G. Spearpoint, R.A.F.O., Royal Air Force Station, Henlow, Beds., and W. O. H. Stanway, Royal Air Force Station, Henlow, Beds. Dated Oct. 21st, 1937. No. 28,651.

The lift of the wings of an aircraft is claimed to be increased by an arrangement in which air is collected by one or more intake chambers situated in the airscrew slipstream, the mouths of which chambers are divided into concentric orifices each communicating with the sections of a continuous slot extending along the wing.

506,007. *Improvements in or relating to a Method of and Means for Reducing Surface Friction between a Solid and a Fluid.* Payn, H. J., Monaco, Hersham Road, Walton-on-Thames, Surrey. Dated Nov. 20th, 1937. No. 31,996.

It is proposed to discharge exhaust gas through nozzle orifices of contracting form disposed in a ring round the nacelles as near as possible to the nose, the

nozzles being disposed so that the gas is discharged tangentially over the surface. The gas is discharged at a speed in excess of the normal speed of the air over the surfaces concerned.

AIRCRAFT—CONSTRUCTION.

501,281. *Improvements in or connected with the Construction of Wings for Aircraft.* The Supermarine Aviation Works (Vickers), Ltd., and Smith, H. C., both of the Company's Works, Woolston, Southampton, Hants. Dated Aug. 23rd, 1937. No. 23,050.

The proposed wing has a single spar and a hollow stressed skin leading edge attached to the top and bottom of the spar in combination with a wall in the leading edge forward of the spar and permanently attached in a liquid-tight manner to the leading edge to form a complete tank in the leading edge independantly of the spar. The combined tank and stressed skin leading edge can be detached.

497,289. *Improvement relating to Means for the Controlling of Trailing Lines, Especially from Aircraft.* Taylor, E., 58, Minley Road, Cove, Farnborough, Hants. Dated June 17th, 1937. No. 16,890.

In order to prevent the trailed line from lashing about while not offering excessive drag when the remote end of the line has its direction changed, as in refuelling, the line has a collapsible drogue closing in one direction but opening in the other. A knife is carried so that the line may be cut when necessary.

497,274. *Improvements in Aeroplanes.* Robertson, J. H., 1, Albemarle Street, Piccadilly, London, W.1. Dated June 15th, 1937. No. 16,599.

The aeroplane proposed is of the all-wing type and has a deep central section, the outer wings being tapered. The inner section of these wings have the same chord as the centre section but tapering to the outer sections, which latter are provided with double ailerons throughout their length. Engines are provided at the junctions between the centre and inner sections and at the junctions between the inner and outer sections.

497,413. *Improvements in or relating to Wing Attaching Hull Superstructure.* United Aircraft Corporation, 400, South Main Street, East Hartford, Connecticut, U.S.A. Convention date (U.S.A.), March 17th, 1936.

The aircraft has the wing situated above the hull and the connecting arrangement consists of bulkheads in the hull with frames extending above the bulkheads and connections between these and the wing spars. A resilient connection is provided between each spar and the bulkhead extension. Diagonal tension members are secured to each bulkhead and extend upwards in the form of an A frame and are connected to the wing spars.

501,947. *Improvements in Thin Sheet Covered Aircraft Bodies, Wings and the Like.* A.T.S. Co., Ltd., 3/4, Clement's Inn, Strand, London, W.C.2, and North, J. D., Hill House, Eaton, Norwich, Norfolk. Dated Sept. 10th, 1937. No. 4,862.

The aircraft component embodies thin sheet covering of metal or other material of high tenacity stiff longitudinal stringers secured to the covering and main transverse frames which extend to and are secured to the covering characterised by this that transverse frames intermediate the main transverse frames are of

such a size that their outer edges or flanges extend only to the inner edges or flanges of the stringers.

502,322. *Improvements in Aircraft Construction.* Kammer, G. S., 50, Quai Gustave Ador, Geneva, Switzerland. Dated July 14th, 1938. No. 20,957.

It is proposed to construct an aeroplane wing by using a number of plate members extending from the upper to the lower surface and running in a zigzag from one edge to the other, each member being bent to constitute substantially straight sections running alternately parallel and perpendicular to the centre line of the aerofoil and adjacent members being connected at the bends between adjacent sections.

504,290. *A Device for Reinforcing Openings in Plywood Structures.* Gaspar, F., XIV Hungarian Korut 93, Budapest, Hungary. Dated Oct. 22nd, 1937. No. 28,904.

It is proposed to sandwich a sheet of metal between plies of this wood and extending inwards from the margin of an opening formed in the wood, the sheet having a corresponding opening with a stiffened edge. The metal sheet may be secured by nails.

507,395. *Improvements in and relating to Cabins for Aircraft.* Junkers, Flugzeug-und-Motoren-werke, Aktiengesellschaft, 39, Junkersstrasse, Dessau, Anhalt, Germany. Convention date (Germany), Oct. 28th, 1937.

In a pressure-tight cabin a number of openings which are normally closed are provided in the walls for admission and egress. Two at least may be provided so as to ensure that escape will always be possible. The openings may be located in directly opposite positions either one on each side or one on the top of the cabin and one on the bottom.

506,528. *Improvements relating to Folding Wing Aircraft.* General Aircraft, Ltd., The London Air Park, Feltham, Middlesex; and Williams, D. L. H., and Crocombe, F. F., both of the Company's address. Dated Nov. 29th, 1937. No. 32,979.

This is a wing folding device for aircraft with a tricycle chassis. In this case the centre of gravity is displaced rearwards, and machines with this type of chassis would tip backwards. It is proposed to use a separate retracting wheel in the rear portion of the fuselage so that the machine will still be approximated horizontal even with the wings folded. The wheel may project sufficiently to protect the tail in a tail down landing when the wings are extended.

506,915. *Improved Aircraft Construction.* Andrews, W. R., 234, Wokingham Road, Reading, Berkshire. Dated Nov. 6th, 1937. No. 30,518.

The aircraft has the centre section of the wing of a greater thickness than the two outer portions, the plan form of the three portions being uniform. The zero lift line of the outer portions is displaced from, but parallel to, the zero lift line of the centre section, so a continuous upper wing surface is precluded.

504,933. *An Improved Metal Section for Use in the Construction of Motor Vehicle Bodies and Other Purposes.* Meltz, M., 43, Ormiston Road, Shepherd's Bush, London, W.12. Dated Oct. 29th, 1937. No. 29,604.

The metal section for constructional purposes is of I form and is built up of two sheet metal channels with their webs inturned and their flanges projecting outwards, the head and foot of the I being constituted by sheet metal strips having their edges bent so as to engage the flanges of the channels and the

channels being slidable relatively to at least one of the head and foot members for the purpose of facilitating flexure of the section.

504,980. *Improvements in and relating to Cockpits for Aircraft.* Junkers, Flugzeug-und-Motoren-werke Aktiengesellschaft, 39, Junkersstrasse, Dessau, Anhalt, Germany. Convention date (Germany), June 4th, 1937.

It is proposed to provide the cockpit with domed windows of a size sufficient to accommodate the head of at least one man, and being free from obstructions such as a gun. These domes are disposed laterally in relation to the vertical longitudinal median plane of the cockpits.

505,201. *Improvements in or connected with Wing Construction of Aircraft.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated Nov. 6th, 1937. No. 30,482.

A hollow cylindroid nacelle of streamline form is arranged between the in-board and out-board wing portions, the said wing portions having their outer and inner ends respectively shaped to correspond with the nacelle, and having devices for detachably attaching them to the nacelle.

505,208. *A Method of and Means for Determining the Form and Controlling the Production of Geodesics.* Vickers (Aviation), Ltd., and Wallis, B. N., both of Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated Nov. 8th, 1937. No. 30,577.

The method proposed consists in ascertaining the length of the chords of the neutral axis of the required geodesic from each node to the next, and also the angular relationship of the chords to each other when intersected, setting out the nodal points on a plate, forming locating means on the plate to mark the nodal points and form the plate into a template, applying fittings of suitable form, forming necessary holes and slots, and finally removing and assembling the structural elements so formed.

AIRSCREWS.

504,162. *Improvements in or relating to Propeller Driving Gear for Aircraft.* Dornier-Werke G.m.b.H. and Dr. Ing. C. Dornier, Friedrichshafen, Lake Constance, Germany. Convention date (Germany), June 8th, 1937.

This specification describes a method by which pusher propellers situated on the wings of aircraft may be raised from their normal position. This is stated to be advantageous in the case of a flying boat taking off. The arrangement proposed consists of bevel wheels which are arranged so that the shaft can swivel vertically from a point at the centre of one of the wheels.

501,467. *Improvements in or relating to Blade-Wheel Propellers.* Voith, W., Voith, H., and Voith, H., trading as the firm of J. M. Voith, Heidenheim an der Brenz, Wurthemberg, Germany. Convention dates (Germany), Dec. 9th, 1936, and March 12th, 1937.

The blades of the proposed propeller oscillate during the rotation of the wheel about axes parallel to the wheel axis. The plane containing the leading edge and the axis of the blade located at either end of the diameter of the wheel perpendicular to the direction of propulsion is perpendicular to the said diameter. The radius vectors of the moving blades, moving opposite to the propulsion direction, intersect the wheel diameter that is perpendicular to the direction of propulsion at points nearer to the centre of the wheel than the radius vectors of the blades in other positions.

507,393. *Improvements in or relating to Blade-Wheel Propellers.* Voith, W., Voith, H., and Voith, H., Heidenheim an der Brenz, Wurthemberg, Germany. Convention date (Germany), Dec. 8th, 1937.

A spindle bearing for blade-wheel propellers with blades oscillating about their longitudinal axes and with roller bearings for the blade spindles. The sleeve of the feathering blade extends throughout the entire length of the blade spindle.

506,722. *Improvements in Swivelling Screw Propellers.* Loth, W. A., 130, Rue Lacourbe, Paris, France, and Guyot, S. M. H., 1, Rue Dante, Paris, France. Dated Aug. 30th, 1937. No. 21,213.

The hub of the propeller is mounted on a driving shaft by means of a universal joint so that the angular position of the propeller can be altered; the joint is so designed that it maintains constant the ratio of the speeds of rotation of the propeller and of the driving shaft at all angles of the propeller shaft to the driving shaft.

505,346. *Device for Mounting Two Aeroplane Propellers Co-Axially and with Reverse Directions of Rotation.* Barbaron, M. J. B., 28, Boulevard d'Argenson, Neuilly-sur-Seine, France. Convention date (France), March 23rd, 1938.

The hub part of the rear propeller is a hollow cylindrical part disposed about a forward extension of the engine casing, the extension carrying a bearing for the shaft of the rear propeller, this bearing being approximately in the plane of rotation of the rear propeller. The front propeller shaft bearing is two concentric rows of balls or rollers with an interposed floating ring serving as a race common to both sets of balls or rollers.

504,877. *Improvements in or relating to Guides for Blade Wheel Propellers.* Voith, W., Voith, H., and Voith, H., Heidenheim an der Brenz, Wurthemberg, Germany. Convention date (Austria), Aug. 6th, 1937.

This relates to a guide beneath a blade wheel provided under a blade wheel propeller mounted on a ship's bottom, the blades of the propeller being arranged in a circle and directed downwards, the propeller rotating about a vertical or inclined axis, the blades oscillating about their own axes. The approximately horizontal guide underneath the propeller is intended to counteract the tendency of the water flow to contract.

ARMAMENT.

505,230. *Improvements in or relating to the Mounting of Guns on Aircraft.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Ordidge, F. H., 5, The Meade, Hill Top, Wilmslow. Dated Dec. 30th, 1937. No. 36,106.

A revolvable gun turret, formed with a slot for the gun, conforms substantially with the tail portion of a wing fillet fairing for which it is substituted. Two such turrets may be used, one on each side of the fuselage, each turret being rotatable about an axis which lies substantially on the line of the side of the fuselage.

CATAPULTING.

506,680. *Improvements relating to Aircraft for Use in Conjunction with Launching Gear.* General Aircraft, Ltd., The London Air Park, Feltham, Middlesex; Williams, D. L. H., and Crocombe, F. F., of the same address. Dated Dec. 9th, 1937. No. 34,149.

This refers to an aircraft with a tricycle chassis, and describes a method of increasing the acceleration of the aircraft for take-off by means of a pull trans-

mitted by a rope to the nose of the fuselage. The direction of the pull is arranged so as to produce a forward pitching moment and so as to produce an automatic correction to yawing. An automatic release may be provided to a mooring rope so that the machine may be released automatically when a pull occurs in the tow rope.

506,737. *Improvements in or relating to the Launching of Aircraft.* Wasley, T. J. J., Ashgarth, Wallington, Surrey. Dated Nov. 29th, 1937. No. 32,892.

It is proposed to construct a tower with a number of stories or platforms, one above the other. In the centre there is a lift by which the aircraft can be lifted to the desired platform. Each story is equipped with a series of compartments each of which is equipped with a catapult. Parts of the platforms may be rotated and the tower may have a high angle conical roof, changing to a mere obtuse one near its lower edge.

CONTROL OF AIRCRAFT.

501,449. *Improvements relating to Means for Rendering Control Systems Irreversible.* Exactor Control Co., Ltd., Exactor Works, Mount Pleasant, Alperton, Middlesex, and Green, O. S., of the Company's address. Dated July 29th, 1937, No. 21,040; and July 6th, 1938, No. 20,034.

This may consist of a push-pull system in which forces in the receiving side cannot reach the transmitting side. A receiver piston rod attached to a double-acting piston extends to one side thereof through one wall of the cylinder, and being connected to the receiver operates in tension and compression to move the receiver, and wherein a transmitter piston rod, extending through the other end of the cylinder, is connected with the transmitter so as to be moved thereby in tension and compression and has lost motion connection with the said piston so as to operate valve means controlling liquid flow through the passage interconnecting the two sides of the piston, whereby movement of the transmitter in either sense can open the valve and move the receiver.

497,077. *Improvements in Aircraft.* Spratt, G. G., c/o Coatesville Airport, Coatesville, Pennsylvania, U.S.A. Convention date (U.S.A.), March 4th, 1936. Application void.

The aircraft has a fuselage and a wing mounted on it above the centre of gravity. The wing can be tilted relatively to the fuselage so as to produce lateral tilting of the aircraft. There is means on the fuselage to produce lateral resistance behind the centre of gravity responsive to lateral displacement in order to change direction. The wing may be tilted longitudinally and laterally for control in both these directions.

497,443. *Improvements in Rudders, Aircraft Wings and Like Fluid Re-acting Planes.* Spurr, E., Fagley Cottage, Dunally Park, Walton Lane, Shepperton, Middlesex. Dated June 30th, 1937. No. 18,220.

The wing or rudder has a modified elliptical shape, having the chord length at any point in the span equal to the chord length at the corresponding point in the span of a basic elliptical plane having the same span principal chord and aerofoil shape, but the locus of points distant a predetermined fraction of the chord from the leading edge is a straight line or two straight lines, the predetermined fraction referred to being the distance of the centre of pressure from the leading edge. The rudder has its turning axis on the straight line referred to and has a contour corresponding to an end portion of the wing shape.

502,093. *A New or Improved Means for Operating Flying or Other Controls of Aircraft, Airships, and Other Ships and Vehicles.* Saunders, R., 100, Wood Lane, Kingsbury, London, N.W.9. Dated Sept. 9th, 1937. No. 24,591.

It is proposed to use a control rod which by rotation operates one control and by longitudinal movement operates another, each movement being unaffected by the other.

501,463. *Improvements in or relating to Aircraft Wing Flaps.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks. Dated Oct. 7th, 1937. No. 27,242.

The wing has at its trailing edge lower and upper flaps which can be turned downwards and upwards respectively. The lower flap above may be operated, or both flaps together.

501,494. *Improvements in Dual Controls for Aircraft.* Ascanelli, A., and Zambaldi, E., both of Via Andrea Bafile, S. Rome, Italy. Convention date (Italy), May 31st, 1937.

This is a device intended for connecting and disconnecting the dual controls of aircraft. A lever controls a group of toothed couplings for the elevators, the rudder bar and ailerons, all these couplings being engaged in the mid position of the lever, while for each other position a group at least of couplings is engaged, said group of couplings corresponding to one of the two controls of the dual control.

501,699. *Improvements in or relating to Control Mechanism for Aircraft.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex; Lobelle, M. J. O., Ludlow, 298, Langley Road, Langley, Bucks; Huxley, M. F., 74, Ellerman Avenue, Twickenham, Middlesex. Dated March 28th, 1938. No. 9,476.

This is a method for operating a control with mechanism comprising a three-armed lever, one arm connected to cockpit operating means, a second arm movable with the first, a third arm movable about the lever axis and connected with the second arm by a radius rod, and by a link with the control element so that oscillation of the lever will move the control element about its axis. A mechanism is provided by an auxiliary means so that an initial angular movement is imparted to the control element so that the ultimate movement is greater or less than that which would result from any given movement of the main mechanism according to the relative direction of the secondary movement.

502,330. *Improvements in the Controls of Aircraft.* Arado Flugzeugwerke Gesellschaft mit beschraenkter Haftung Brandenburg (Havel), Germany. Convention date (Germany), Dec. 7th, 1937.

It is proposed to couple the throttle control with the control for a landing flap so that when the throttle is opened the flap is moved to the best take-off position. When the flap is retracted the throttle has no effect on it.

504,336. *Improvements in and relating to Supporting Surfaces for Aircraft.* Junkers Flugzeug-und-Motoren-werke Aktiengesellschaft, 39, Junkers-strasse, Dessau, Anhalt, Germany. Convention date (Germany), Oct. 28th, 1937.

The wing has an auxiliary wing and mechanism is provided by which the latter is moved to an extended position, and at the same time the angle of incidence is progressively increased. When the auxiliary wing is fully extended while the chord of the wing unit is only slightly modified, the angle of incidence of the auxiliary wing is considerably modified.

504,535. *Improvements in or relating to Controlling Aircraft.* Bayerische Flugzeugwerke A.G. Hannstetters-strasse 118a, Augsburg, Germany. Convention date (Germany), Sept. 20th, 1937.

Arrangements are made for sucking away the boundary layer from the thick profile in the inner part of the wing during high speed flight, and from the outer portion when landing. It is proposed to effect the change over automatically by an auxiliary surface placed in front of the wing which alters its position from low speed flight to high speed and, in doing so, operates appropriate valves.

504,788. *Improvements in Aeroplanes.* A. V. Roe and Co., Ltd., Newton Heath, Manchester 10, and Chadwick, R., of the Company's address. Dated Oct. 27th, 1937, No. 29,321; and Oct. 27th, 1937, No. 29,322.

On pulling down the flap devices on an aeroplane wing it is proposed to move automatically a member on the tailplane which corrects for the alteration in pitching moment. Hinged flaps are fitted on the tailplane ahead of the elevators and are interconnected with the wing flaps.

506,714. *Means for Shifting Flaps on Aircraft.* Arado Flugzeugwerke Gesellschaft mit beschraenkter Haftung, Brandenburg (Havel), Germany. Convention date (Germany), Jan. 25th, 1938.

This concerns the type of flap which is projected rearwardly from the main wing and swung downwards at the same time. The flap is connected to the rear of two double armed levers pivotally connected centrally. One lever has, centrally, a pin movable in a guide in the main wing and is connected forwardly with actuating means. The other lever is connected at its rear with the nose of the flap and at its forward end is guided in a second guide in the main wing.

507,103. *An Improved Air Brake for Aircraft.* The Fairey Aviation Co., Ltd., North Hyde Road, Hayes, Middlesex, and Flt. Lieut. L. H. Hilton, Links, Gordon Avenue, Stanmore, Middlesex.

The proposed brake consists of a retractable flat plate to be projected from the upper wing of an aircraft, in other words, a spoiler, so that the raising of the plate is effected by means acting in conjunction with the means for lowering the chassis. The plate may be pivoted to the front spar of the wing by links or it may be raised by the inflation of an air tube.

506,074. *Improvements in Stabilising Devices.* Gianoli, M. L., 17, Rue Chartran, Neuilly-sur-Seine (Seine), France. Dated Nov. 29th, 1937. No. 32,950.

Automatic stabilising device for aerial movable objects, having a main surface pivoted on the movable object having an auxiliary surface pivoted on the main surface, and a kinematic device connecting the two compelling the auxiliary device to modify its position relatively to the main surface when the latter itself modifies its position relatively to the body of the movable object.

506,136. *Improvements in or relating to Wings for Aircraft.* Gliwa, M., 3631, South Hermitage Avenue, Chicago, Illinois, U.S.A. Dated Sept. 14th, 1938. No. 26,776.

In an aeroplane of normal form, it is proposed to fit hollow wings open at their trailing edges. Inside each wing there is carried an auxiliary wing formed in sectors pivoted on apices upon a common vertical pivot. When this auxiliary wing is extended it resembles a sector of a circle between the rear of the wing and the fuselage.

503,908. *Means for Actuating Ailerons of Aircraft.* Arado Flugzeugwerke Gesellschaft mit beschraenkter Haftung, Brandenburg (Havel), Berlin, Germany. Convention date (Germany), July 11th, 1938.

The ailerons are each movable rearwardly together with a flap, and there is provided a number of pivotally connected links, the first of which is pivotally mounted on the main wing, and the last is pivotally mounted on the outrigger serving for extending the flap, and that at the pivot points rotatable bodies are mounted on pivots at right angles to the plane of movement, which bodies are interconnected by members extending parallel to the links and are connected with the aileron by a push rod connected to a lever, so that the aileron is controllable independently of the position of the outrigger by an actuating lever.

505,937. *Improvements in or relating to Means for Mounting or Supporting Servo Motors.* Askania-Werke Aktiengesellschaft vormals Centralwerkstatt Dessau und Carl Bamberg-Friedman, Kaiserallee 87/88, Berlin-Friedman, Germany. Convention dates (Germany), Feb. 8th, 1937, and Aug. 6th, 1937.

A servo motor for aircraft controls, including a servo motor and a shaft rotated by it, in particular, in connection with a rudder, the servo motor housing is pivotally mounted about a first axis and there being a rod journaled on the servo motor housing about an axis parallel to or co-axial with said first axis and means to secure said rod to the control shaft or the mounting thereof or with a part of the base suitable for taking up thrust and tension forces so that the greatest part of the force reaching on the said housing is taken up by said rod.

503,022. *Improvements relating to the Control Surfaces of Aircraft.* Robinson, P. P., Penhoet, Flaghead Road, Canford Cliffs, Bournemouth, Hampshire, and Foss, J. F., Trentham, Keydell Avenue, Horndean, Portsmouth, Hampshire. Dated Sept. 29th, 1937. No. 26,370.

This refers to flaps in which the flap forms part of a linkage having a rear link pivoted to the rear of the wing and to a point on the flap, the forward end of which is movable fore and aft on the wing. It is proposed to pivot the link to the flap near the trailing edge and to move the flap from the folded position to a position in which it extends rearwardly beyond the wing trailing edge.

DE-ICING.

501,201. *Means for Detecting Ice Forming Conditions Encountered by Aircraft.* Langley, T. W., and Tecalemet, Ltd., both of the Company's Works, Great West Road, Brentford, Middlesex. Dated July 22nd, 1937. No. 20,336.

There is a movable member and a means for detecting the presence of ice on it, the member being moved so that part of it passes successively an exposed position where ice may form. The ice detecting means comprises at least one contact member which engages the drum. Both the drum and the contact member may be electrically conducting and the indication may be given by electrical means, as the ice formed will break the contact. Or, alternatively, the ice formed on the drum may be arranged by a device so as to make the electrical contact.

506,843. *Means for Indicating Ice Formation.* Goldschmidt, R., 84, Hillfield Court, Belsize Avenue, London, N.W.3. Dated Jan. 12th, 1938. No. 1,087.

The indicator proposed consists preferably of a member which is caused to vibrate by means of electrical impulses, this vibration being impeded if ice forms

on the member; the member may be a diaphragm and its natural frequency is arranged to be higher than the frequency at which it is normally caused to move. The indicating means comprise electrical contacts which, when closed, short-circuit an indicating device, and they are arranged to remain open when the movement of the diaphragm is impeded by ice.

506,179. *Improved Means for Preventing the Formation of Ice on Aircraft.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby. Dated Nov. 24th, 1937. No. 32,396.

The cooling air from the engine is led through a conduit or conduits situated along the leading edges of the wing or along other parts and terminating at the trailing edges or other suitable places in order to prevent ice formation.

505,772. *Improvements in or connected with Means for Preventing Ice Formation on Control Surfaces of Aircraft.* Headen, L. A., St. Mary's Works, Frimley Road, Camberley, Surrey. Dated Nov. 16th, 1937. No. 31,461.

An air heater on the engine or exhaust pipe communicates with a blower which forces the heated gas through tubes to parts of the aircraft near the hinge joints, from where they impinge as jets on the hinge joints. This hot gas delivery may be controlled.

505,873. *Improvements in and relating to Arrangements for Preventing the Formation of Ice on Aircraft.* Groves, W. W., 30, Southampton Buildings, London, W.C.2. Dated July 14th, 1938. No. 20,925.

The prevention is to be effected by heat from the engine. A distribution chamber of large cross section is located inside the member to be protected and guide passages for a gaseous or liquid heat carrier are conducted along the inner side of the outer skin of the member to be protected. The walls of the distribution chamber form part at least of the passages which conduct the heat carrier along and in contact with the inner side of the outer skin of the part concerned.

505,433. *Improvements in and relating to De-Icing Equipment for Example for Aircraft.* Goldschmidt, R., 84, Hillfield Court, Belsize Avenue, London, N.W.3. Dated Nov. 5th, 1937, No. 30,436; July 25th, 1938, No. 22,088; and Jan. 12th, 1938, No. 35,445.

It is proposed to arrange that the surface of the part to be de-iced is formed of a skin which can be elastically deformed to a small extent. It is proposed to produce these deformations by impacts or by propagating waves along the surface to be de-iced. It is claimed that these small movements are effective in breaking off forming ice.

505,094. *Method of and Means for Distributing Fluid to Prevent Accretion of Ice on the Wings and Other Exposed Parts or Surfaces of Aircraft.* Dunlop Rubber Co., Ltd., 32, Osnaburgh Street, London, N.W.1; Wright, J., and Trevaskis, H., both of the Company's Works, Fort Dunlop, Erdington, Birmingham, Warwick.

The liquid is fed under pressure to a device incorporating a valve for regulating the quantity flowing. The valve can be by-passed so that full pressure may be used, or an unrestricted flooding flow of liquid delivered to the part or surface or simultaneously to a number of parts or surfaces.

ENGINES.

497,156. *Controlling Aircraft Engines.* Lusty, I., Caerleon, Monmouthshire. Dated June 15th, 1937. No. 16,568.

Airscrew control mechanism for synchronising aero engines with variable pitch airscrews has one datum speed device for each engine, each working at a predetermined speed. The speed can be adjusted of all these devices together and there is a device for each engine which varies the pitch-changing mechanism when the engine speed varies from that of the device, so as to bring the engine speed again to that of the device The datum speed devices consist of A.C. synchronous motors supplied from a single source of current. The airscrew control mechanism consists of a mechanical differential device, one element of which is driven by the engine, another by the electric motor, and a third element is connected with the pitch control gear.

502,317. *Improvements in or relating to the Exhaust Systems of the Internal Combustion Engines on Aircraft.* Schneebeli, H., 52, Rue Armand Sylvestre, Courbevoie, France. Convention date (France), July 2nd, 1937.

The exhaust system employs a streamline cowling which latter is a double-walled casing into which the exhaust gases are discharged, and from which they escape through perforations in spacing members. These latter also form stays and are tubular and lead to the outer air. A separate element may be used for each cylinder of a multi-cylindered engine.

501,750. *Cowling for Aircraft Engines or for Radiators or the Like for Aircraft Engines.* Arado Flugzeugwerke Gesellschaft mit beschraenkter Haftung, Brandenburg (Havel), Germany. Convention date (Germany), Aug. 31st, 1937.

This is a cowling for an aircraft engine or for an annular radiator, on the rear edge of the cowling there are arranged air louvres which open outwards. The louvres are coupled with each other by spreading rings, the diameter of which can be positively increased or decreased. The louvres are opened by increasing the diameter and closed by reducing it. The diameter of the ring is increased by arranging that the ends are moved relatively to each other by the swivelling ends of two link bars.

504,539. *Arrangement of Aircraft Engines.* Sir W. G. Armstrong-Whitworth Aircraft, Ltd., and Lloyd, J., of the Company's Works, Whitley, Coventry, Warwickshire. Dated Sept. 30th, 1938. No. 28,412.

One or more air-cooled engines having X-like banks of in-line cylinders are supported in the interior of an aeroplane wing. Each cylinder bank has its own air duct extending from the leading edge of the wing to the rear of the bank, across which the cylinders extend. The duct may continue to the trailing edge or may communicate with a space in the wing at the rear of the engine which has an outlet at the trailing edge.

504,747. *Improvements in or connected with Aircraft Engine Cowlings.* Vickers (Aviation), Ltd., Pierson, R. K., and Ellis, D. L., all of Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated Oct. 30th, 1937, No. 29,726, and Oct. 11th, 1938, No. 29,412.

This is a cowling having a spinner which latter is formed with a concave portion adjacent to its rear edge so as to deflect the air radially outwards. The cowling may have means consisting of a rotor driven at an increased speed relatively to the spinner so as to increase the outflow of air through the gap. The interior of the cowling may have intakes or scoops facing forward.

504,069. *Engine and Change Speed Power Transmission on Both Sides.* Cotal, J., 2, Rue de Saint Marceaux, Paris, Seine, France. Convention date (France), March 11th, 1937.

The engine propeller shaft drives the supercharger on one side and the propeller on the other through variable gear trains of epicycloidical type controlled by the pilot. There is a variable gear for the supercharger with the view of increasing supercharge. The supercharger is driven by a gear to increase its speed. A reduction gear drives the propeller in which is incorporated a two-speed gear electrically controlled.

506,468. *Improvements in and relating to the Cooling of the Compressed Gaseous Charges of Internal Combustion Engines.* Junkers, Flugzeug-und-Motoren-werke Aktiengesellschaft, 39, Junkersstrasse, Dessau, Anhalt, Germany. Convention date (Germany), July 5th, 1937.

This is a proposal for cooling the gaseous charges of internal combustion engines between the engine and the blower. The gas may be passed through the wing, especially parts which are subject to icing, or a fin may be used as a distributing chamber from which the gas is led to cooling passages in the leading edge.

506,491. *Improvements in Means for the Control of the Engines of Multi-Engine Aircraft.* Arado Flugzeugwerke Gesellschaft mit beschrankter Haftung, Brandenburg (Havel), Germany. Convention date (Germany), Feb. 17th, 1938.

In aircraft with engines arranged on opposite sides of the longitudinal axis, for cutting out an engine or engines in order to bring about balance of the aeroplane, a circuit is automatically closed on the stalling of one engine, which circuit includes a relay which effects engine control. There are also two switches, one of which is controlled by a pitot tube and the other is controlled by the difference in the rotational speeds of the engines.

506,645. *Improvements in or relating to the Mounting of Aircraft Engines and Propellers.* Elliot, A. G., Holmwood, Quarndon, Derby. Dated Nov. 30th, 1937. No. 33,087.

In the case of engines mounted in the structure of an aeroplane it is proposed to mount the engine by means of trunnion pins coaxial or parallel with the crankshaft, carried by resilient means in bearings in the aircraft structure, the resilient means resists torque reaction. The propeller and shaft are rigidly mounted in bearings on the aircraft structure independently of the engine, and are driven by a universally jointed transmission shaft. Frictional or hydraulic damping of the engine movements may also be used.

506,699. *Improvements in and relating to the Utilisation of the Exhaust Gas Energy of Aircraft Engines for Propulsion Purposes.* Junkers, Flugzeug-und-Motoren-werke, Aktiengesellschaft, 39, Junkersstrasse, Dessau, Anhalt, Germany. Convention date (Germany), July 1st, 1937.

The gas is discharged into the atmosphere in a direction opposed to that of flight. The exhaust gas from each cylinder discharges into a separate pipe having a nozzle. This has an aperture of such a size as to increase the pressure in the pipe, thereby increasing the emergent velocity and the propulsion force. The taper ratio of the nozzle varies between 0.3 and 1 and the capacity of the exhaust pipe varies between 0.3 and 1 of the swept volume of the working cylinder.

506,146. *Improvements in Radiators for Aeroplanes and the Like.* Belaieff, J. F., Delaney, C. T., and Gallay, Ltd., all of the Company's address, Edgware Road, Cricklewood, London, N.W.2.

In radiators carried inside aeroplane wings it is proposed to use radiators arranged in a V or double V formation. The air inlets on the leading edge are to be controlled, the air outlets being at the trailing edge.

506,333. *Exhaust Pipes for Internal Combustion Engines of Aircraft.* Ellor, J. E., Grandell, South Drive, Chain Lane, Mickleover, Derby. Dated Sept. 24th, 1937. No. 25,944.

The exhaust gases from a group of cylinders are discharged through a number of expansion boxes, the expansion boxes being shaped as a flattened streamline member lying in the airstream. The gases are discharged through tapered and restricted nozzles projecting backwards.

506,702. *Improvements in or relating to Cowlings for Air-Cooled Aircraft Engines.* Mercier, P. E., 11, Rue Jacques Dulud, Neuilly-sur-Seine (Seine), France. Dated Feb. 18th, 1938. No. 5,201.

In this cowling it is proposed to place exhaust members of the engine in front of the rear edge of the outlet aperture so that they may be cooled by the air which has already circulated over the engine. The exhaust members may form part of the forward profile of the cowling or they may be disposed in the outlet aperture, or they may be surrounded by an envelope having an inlet aperture in front of the cowling and an outlet aperture leading into the discharge conduit.

505,967. *Engine Arrangement in Multi-Engined Aircraft.* Blume, W., Ziesser Landstrasse 16, Brandenburg (Havel), Germany; and Arado Flugzeugwerke Gesellschaft mit beschraenkter Haftung, Brandenburg (Havel), Germany. Convention date (Germany), Jan. 6th, 1938.

It is proposed to mount the engines partially within the fuselage and partially within the wing, the propellers being driven by transmission mechanism. In the case of a V engine the cylinders may be within the fuselage and the crankcase within the wing. If a flat engine is used the crankcase may be located at the wing root, one set of cylinders being in the fuselage, the other in the wing.

506,047. *Improvements in or relating to the Charging of the Cylinders of Internal Combustion Engines.* Jeyler, H., 10, Stockerstrasse, Zurich, Switzerland. Convention date (Switzerland), Oct. 15th, 1937.

Reference is made to application 499,060 in which the energy in the exhaust gas is used to set up in a tube a rapidly moving column of air, the flow of the column being periodically interrupted by a valve. The kinetic energy in the column is converted into pressure energy, the air in this state being admitted to the engine. This specification claims a value of which the diameter is greater than and may be a multiple of the inlet pipe.

503,690. *Improvements in Cooling Arrangements for Air-Cooled Radial Cylinder Engines of Aircraft.* The Bristol Aeroplane Co., Ltd., Fedden, A. H. R., Copley, J. W., and Fortescue, P., all of Filton House, Bristol. Dated Oct. 27th, 1937, No. 29,375; and May 19th, 1938, No. 14,976.

This specification describes cowling for an air-cooled radial engine in which air enters through the front orifice and is discharged partly through an orifice

near the front of the cowl and partly at the rear of the cowl. An exhaust collector is so arranged that it is cooled by the air passing to the orifice near the front of the cowl, and there is a partition to separate the incoming air from the exhaust collector. The exhaust collector is of ring form and is in front of the cylinders.

504,992. *Oil Cooler for Aircraft Engines.* Bayerische Motoren Werke Aktiengesellschaft, Lerchenauerstrasse 76, Munchen 13, Germany. Convention date (Germany), Aug. 4th, 1937.

The proposed oil cooler for radial engines may be mounted in a hollow space in the front end of the engine cowling, the air for cooling may be withdrawn from a chamber in front of the cylinders or from behind them. The areas of the air supply pipes may be controlled manually or by a thermostat.

502,732. *Shutters for Cowlings of Aircraft.* Cowdrey, C. L., Glen Masson, 6, Temple Drive, Nuthall, Nottinghamshire. Dated Sept. 20th, 1937. No. 25,496.

This is a discharge orifice for air from the cowling of aircraft provided by at least four shutters hinged together, the lines of the hinges meeting about a point in front. In one position the central shutters form a portion of a cone with an opening at the rear, the other shutters lying flush with the cowling; in another position the whole of the shutters form the part of the cone with a larger opening to the rear.

503,073. *Improvements in and relating to Aircraft Motor Cowling.* Theodorsen, T., 3321, Chesapeake Avenue, Hampton, Virginia, U.S.A. Dated July 30th, 1937. No. 21,237.

This radial engine cowling has a circular air inlet in front in the normal position and an annular air outlet also near the front situated at the point of maximum low pressure. Adjusting means are provided to adjust the degree of opening of the air outlet. The cowling may have more than one air outlet, at least one of which is located ahead of the point of maximum negative pressure.

FABRIC.

504,565. *Improvements in or connected with Means for Attaching Fabric to Aircraft Members.* Vickers (Aviation), Ltd., and Stevenson, B. E., Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated Oct. 26th, 1937. No. 29,206.

The parts supporting the fabric are formed with grooves into which the fabric is pulled down. It is held in position by needles, the ends of which pass through the fabric and through holes at the bottom of the grooves. One end of the needle may be cranked or joggled.

HYDRAULICS.

502,496. *Pipe Joints.* Cowdrey, C. L., Glen Masson, 6, Temple Drive, Nuthall, Nottinghamshire, England. Dated Sept. 20th, 1937, No. 25,497; and June 22nd, 1938, No. 18,576.

One of the pipes to be jointed has an end portion into which the end of the other is adapted to pass. Sandwiched between the pipes is a ring member which is located axially, but free to move radially with reference to one of the pipes, the inner pipe makes a push fit into the said ring (if the ring is carried by the outer pipe) or the inner pipe and ring together make a push fit into the outer pipe (if the ring is carried by the inner pipe) with a rounded portion which

makes contact with the ring or outer pipe as the case may be and allows some universal and telescopic movement to the pipes with reference to each other, the said rounded portion sliding on the surface with which it is in contact.

MISCELLANEOUS.

497,289. *Improvements relating to Means for the Controlling of Trailing Lines, especially from Aircraft.* Taylor, E., 58, Minley Road, Cove, Farnborough, Hampshire. Dated June 17th, 1937. No. 16,890.

For the purpose of preventing a trailing line from lashing about in flight the line has a parachute drogue carried in such a way that the drogue will remain open when drawn through the air by the line in one direction, but closes on movement in the reverse direction and re-opens upon return to the original direction. A bulge is formed in the line entraining a pivoted knife so as to cause the knife to cut the wire.

506,067. *Improvements in or relating to Means for Reducing Torsional Oscillations in Transmission Systems.* Scott-Paine, H., The British Power Boat Co., Hythe, Southampton, Hampshire; and Wilson, W. K., Stag Lane Aerodrome, Edgware, Middlesex. Dated Oct. 20th, 1937. No. 28,629.

The transmission drive has flexible connecting members situated between each member and heavy masses such as fly wheels or gears, at the gearbox, and arranged so that the moment of inertia of the masses at the gearbox is sufficiently large compared with the sum of the moments of inertia of the members of the drive, that the higher of the two resulting fundamental frequencies of natural vibration is not greater than twice the lower of the said frequencies, and preferably not 50 per cent. higher.

505,654. *Improvements relating to Valve Arrangements in Fluid Pressure Systems.* Dowty, G. H., Arle Court, Cheltenham, Gloucestershire. Dated Oct. 11th, 1937. No. 27,576.

In a hydraulic system with a circuit which includes a valve and union device for making a temporary branch connection to the circuit so constructed that making the said temporary connection moves the valve so as to open it for flow through said branch against which flow it is normally closed, and to close it against flow through the circuit for which flow it is normally open.

505,431. *Improvements relating to Hinge Mountings for Doors, Panels, Hatchways, or the Like.* Hudson, R. J. H., Yennadon House, Dousland, South Devon. Dated Oct. 7th, 1937, No. 27,298; and Aug. 12th, 1938, No. 23,853.

Provision is made for the hinge line of the door to be displaced relatively to the support. The first part of the hinge arrangement is a movable arm carried by the support on a part axis at right angles to the displacement. The second part is a swivel portion pivoted to the arm about a second axis, the orientation of which is varied by the movements of the arm and also pivoted to the door about a third axis so that the displacement and swinging are independent.

503,458. *Means for Controlling by Fluid the Brakes of Aircraft and Other Vehicles.* Société "Olaer," 118, Avenue des Champ Elysées, Paris, France, and Mercier, J., of the same address. Dated July 5th, 1938. No. 19,877.

This is a pressure reducing valve distributor having a movable supporting body containing expansion chambers, closing valves for these chambers, and pushers for operating these valves may be displaced and may come in contact with an abutment which is tiltable at will.

505,202. *Improvements in or connected with Stowing Tanks in Aircraft Wings.* Vickers (Aviation), Ltd., and Wallis, B. N., Weybridge Works, Brooklands Road, Weybridge, Surrey. Dated Nov. 6th, 1937. No. 30,483.

The proposed means for stowing tanks in the wings, which is removable from the body, or form a stub wing, is to provide a free space or spaces for the tanks and there are devices by which the tank or tanks can be slid into or out of the wing when it is detached. When the tanks are stowed in position and when the wing is attached to the aeroplane the necessary pipes may be connected.

MODEL AIRCRAFT.

505,256. *Improvements in Toy Aeroplanes.* Rigby, W. 47, Valleyfield Road, Streatham, London, S.W. Dated Nov. 4th, 1937. No. 30,261.

The toy undercarriage has arms carrying wheels which are pivotally mounted on the body of the aeroplane about a transverse axis, and formed with a lever extended longitudinally of the aeroplane, the said lever being attached to the body by no direct means so that it yields on impact.

505,257. *An Improved Winding Gear for the Driving Rubber of Toy Aeroplanes.* Wallis Rigby, 45, Valleyfield Road, Streatham, London, S.W.16. Dated Nov. 4th, 1937. No. 30,264.

The winding gear has back and front members spaced apart to enable the propeller to rotate, a cradle to support the aeroplane body at its nose, and a winding gear with an external handle with an internal projection to engage the propeller.

PARACHUTES.

506,525. *Improvements in or relating to Pack Parachutes.* Eschner, J., 20, Franklinstrasse, Vienna, Austria. Dated Nov. 29th, 1937. No. 32,959.

The canopy fabric of the parachute is symmetrically folded in and rolled into the packing position from the edge towards the inner surface of the apex characterised in that the fabric folded crosswise into a square middle field is rolled into two longitudinal rolls lying on both sides of a diagonal, and from the ends of the said rolls is rolled into two transverse rolls while the shroud line and load lines are placed on the inner surface of the apex with their free ends projecting from the middle of the pack.

497,448. *Improvements in Parachutes.* Evans, J. J., 48, Porchester Terrace, London, W.2; and Quilter, J. R. C., Stadium Works, Woking, Surrey. Dated August 20th, 1937. No. 22,891.

The parachute has webs or gusset pieces of triangular shape acting as individual shroud lines and connected together at or near the axis of the parachute so as to occupy radial planes when the parachute is open, characterised by the fact that the webs or gusset pieces extend inside the canopy, leaving a free space above them for internal air movement.

ROTORCRAFT.

501,472. *Improvements in Flying Machines.* Hovland, A. N., Bestun, Oslo, Norway. Dated Jan. 24th, 1938. No. 2,282.

The machine is adapted to ascend and descend under the influence of wings rotatable about a vertical axis after release from their normal transverse position, and tilting of one wing about its longitudinal axis, in combination with a stabilising rotor positioned above the wings and capable of autorotation to stabilise the machine during the transition of the supporting planes from rotational movement into fixed transverse position.

504,493. *Aeroplane.* Laanti, M., Haapasaari, Kotka, Finland. Dated March 21st, 1938.

The flying machine has a lifting and propelling device consisting of two or more vaned wheels rotating about an axis which is at right angles to the direction of flight. A cowling is provided which has an adjustable opening for controlling the propelling force.

504,718. *Improvements in or relating to Rotary Wing Aircraft.* Hutchison, H. H., and Gibson, J. J., 118, Hillside Gardens, Barnet, Herts. Dated Oct. 26th, 1937. No. 29,173.

Air or steam under pressure is conveyed up the centre of the rotor axle, and along the blades. It is expelled from the trailing edge of a tube with the outboard end blocked or sealed, the tube extending out beyond the end of the wings. A frictionless valve is provided at the top of the axle to prevent steam escaping at the joint.

504,894. *Improvements in and relating to Aircraft Sustaining Rotors.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2, and Bennett, J. A. J., 67, Grove Way, Esher, Surrey. Dated Nov. 8th, 1937. No. 28,665.

In lifting rotors, the blades are independently articulated to the hub respectively for flapping and combined leading-and-lagging and pitch varying movements, and wherein an intermediate articular member, to which a rotor blade is connected by a flapping pivot is connected to the hub by an inclined pivot permitting the combined leading-and-lagging and pitch varying movement.

504,942. *Improvements in and relating to Aircraft Sustaining and/or Lifting Rotors.* Josselyn, J., 376, Strand, London, W.C.2; and Blake, R., Bush House, Aldwych, London, W.C.2. Dated Nov. 2nd, 1937. No. 30,011.

The rotor has a rotary hub member, a single blade radially disposed pivotal means connecting the hub to the blade and providing for flapping in a path transverse to the rotational path, and a non-lifting counterweight counterbalancing the blade and means controllable in flight for varying the position relative to the aircraft of the path swept by the rotor blade. The counterweight may be rigidly or pivotally connected to the hub.

506,404. *Improvements in and relating to Helicopters and Gyroplanes.* The Cierva Autogiro Co., Ltd., Bush House, Aldwych, London, W.C.2; and Bennett, J. A. J., 67, Grove Way, Esher, Surrey. Dated Nov. 26th, 1937, No. 32,731; and March 9th, 1938, No. 7,367.

The rotors of the proposed machine have two or more blades each which are co-axial or spaced and non-intermeshing, characterised in that paired rotors are so geared together that when a blade of one of the rotors lies in a direction making an angle with the first named direction equal or approximately equal to half the blade-spacing angle. The paired rotors have each a single counterweighted blade, both the blade and the counterweight being free to flap.

TESTING.

507,477. *Methods and Means for Testing Rotary Bodies, especially Wheels and/or Tyres.* Dunlop Rubber Co., Ltd., 32, Osnaburg Street, London, N.W.1; Williams, J. I., and Broadbent, F. G., of the Company's Works at Fort Dunlop, Erdington, Birmingham, Warwick. Dated Nov. 10th, 1937, No. 30,814; and Aug. 31st, 1938, No. 25,491.

For testing tyres a rotary drum is used which may be of elliptical section mounted on an oblique axis. The tyre is rotated and thrust may be applied to

it acting on parts of it spaced to one side of its median plan, corresponding parts on the other side being free from thrust. The applied thrust may be intermittent.

UNDERCARRIAGES.

505,263. *Improvements relating to Landing Gear Arrangements of Aircraft.* General Aircraft, Ltd., The London Air Park, Feltham, Middlesex, Williams, D. L. H., and Crocombe, F. F., both of the Company's address. Dated Nov. 4th, 1937, No. 34,409, and Dec. 9th, 1937, No. 34,148.

In the case of three-wheeled chassis for aeroplanes having the single wheel in front, it is proposed that this front wheel shall be supported in a manner allowing its retraction into the body of the fuselage for the purpose of reducing drag loads in flight. The wheel may take up a number of positions between retraction and extension and in each position is capable of taking landing loads.

506,527. *Improvements relating to Aircraft Undercarriages.* General Aircraft, Ltd., London Air Park, Feltham, Middlesex; and Williams, D. L. H., and Crocombe, F. F., of the Company's address. Dated Nov. 29th, 1937, No. 32,978; and Dec. 31st, 1937, No. 36,254.

This refers to a folding nose wheel chassis for a tricycle undercarriage. The wheel is carried by a strut pivoted transversely and the mounting can be swung forward about the axis so as to move the wheel into its retracted position inside the nose of the fuselage.

506,719. *Improvements relating to Aircraft Undercarriages.* General Aircraft, Ltd., The London Air Park, Feltham, Middlesex; Williams, D. L. H., and Crocombe, F. F. Dated Nov. 29th, 1937. No. 11,795.

This is a method of folding the nose wheel of a tricycle undercarriage. The wheel is supported by a type of rectangular framework with hinged joints so that the wheel is lifted vertically into the fuselage when folding by a sort of parallel action. The shock absorber spans the framework diagonally.

506,633. *Improvements relating to Aircraft Undercarriages.* General Aircraft, Ltd., The London Air Park, Feltham, Middlesex; Williams, D. L. H., and Crocombe, F. F., of the same address. Dated Nov. 29th, 1937. No. 11,794.

This is an arrangement for folding the front wheel of a tricycle chassis, in which the strut and wheel are folded sideways, being pivoted on the upper part of the strut. Two front wheels may be used, one folding to port and the other to starboard. A worm and wheel arrangement may be used for folding.

505,109. *Improvements relating to Landing Gear Arrangements of Aircraft.* General Aircraft, Ltd., The London Air Park, Feltham, Middlesex; Williams, D. L. H., and Crocombe, F. F., both of the Company's address. Dated Nov. 4th, 1937. No. 30,282.

This specification refers to three-wheel chassis arrangements in which the single wheel is in front. The front wheel is supported in a manner which permits swivelling, but a mechanism is provided for restraining this swivelling as it has been found that there is a tendency for the front wheel to oscillate.

502,970. *Improvements relating to Aircraft Landing Gear.* Dowty, G. H., Arle Court, Cheltenham, Gloucestershire. Dated Sept. 28th, 1937. No. 26,248.

A landing gear is proposed comprising a number of wheels mounted for castoring through 360° and means are provided interconnecting their mountings so as to ensure parallelism in regard to track. Preferably each wheel is carried by a

telescopic strut, the lower part of which is rotatable to allow castoring. The castoring rotation of the wheel may be transmitted to a sleeve mounted on the fixed part of the strut, the sleeves may carry chain wheels which may be connected together by a chain. A twin-wheel unit may be retractable by swinging as a whole on a single axis.

505,375. *Improvements in or relating to Fluid Pressure Brakes.* Bendix Aviation Corp., 105, West Adams Street, Chicago, Illinois, U.S.A. Convention date (U.S.A.), Nov. 11th, 1936.

A fluid pressure braking system comprising a slave unit fed with fluid through a manually operable control valve, which latter is provided with a member which is moved in opening the valve and is subject to the fluid pressure on the slave unit side of the control valve whereby the resistance offered to the movement of the valve varies in accordance with the pressure in the slave unit, and a constricted relief passage provided in connection with the slave unit to release fluid therefrom all the while the brake is being applied, the fluid so released being replaced continuously from the source by way of the control valve.

503,807. *Improvements in or relating to Landing Gear for Aircraft.* The Ribbesford Co., Ltd., Brock House, Langham Street, London, W.1, and Thornhill, P. W., of the Company's address. Dated March 30th, 1937, No. 33,125, and March 23rd, 1938, No. 8,968.

A proposed shock absorber has a pair of tubular members arranged to move relatively in a telescopic sense for shock absorption, rotationally to permit castering. It has resilient means to resist shortening, a piston which displaces liquid as the two members are rotated away from a predetermined angular position, resilient centring means, and damping means to damp the rotational movement away from said angular position.

503,658. *Means for Controlling by Fluid Under Pressure the Brakes of Aircraft and Other Vehicles.* Mercier, J., 118, Avenue des Champs d'Elysees, Paris, France. Dated April 27th, 1938. No. 12,526.

It is proposed to obtain the progressive action of brakes without the assistance of expansion chambers by acting on the outlet of the distributor, preferably on the closing member. This distributor has an outlet passage for exhausting the brakes characterised by the use of additional means which allow the pilot to influence the flow through this passage so as to render progressive the releasing action of the brakes.

503,789. *Improvements relating to Retractable Undercarriages for Aircraft.* Dowty, G. H., Arle Court, Cheltenham, Gloucestershire. Dated Oct. 13th, 1937. No. 27,867.

This undercarriage has a leg and landing element retractable by swinging backwards and upwards. Resilient means such as a spring connected to the leg arranged to accumulate energy during retraction throughout a substantial portion of the retraction movement and to expend this energy during the last part of the retraction movement, so that energy accumulates while the retraction is assisted by aerodynamical forces, and is given out while retraction is opposed by gravitational forces.

502,567. *Improvements in or relating to Tail Supporting Wheels or Their Equivalents for Aircraft.* Cowey, L. E., 4, High Park Road, Kew Gardens, Surrey. Dated Aug. 17th, 1937. No. 22,610.

This is a mounting for a retractable tail wheel having a telescopic compression strut pivotally connected at its lower end with the fork and at its upper end with

a link, which projects forwards of the tail wheel and is pivotally connected with the fuselage at its forward end. Radius rods are connected with the tail wheel and fuselage. The link being movable upwards and forwards about the attachment point to the fuselage, the radius rods, compression strut, tail wheel, etc., may be raised into a position in which they lie wholly or partially within the contour of the fuselage.

507,162. *Improvements in or relating to Fluid Pressure Apparatus for Controlling the Operation of Brakes for Aircraft.* Dunlop Rubber Co., Ltd., 32, Osnaburgh Street, London, N.W.1; Beharrell, G. E., Wright, J., and Trevaskis, H., all of the Company's Works at Fort Dunlop, Erdington, Birmingham, Warwickshire.

The means for operating each pair of inlet and exhaust valves consists of a tiltable lever having at one end a plug to close the exhaust orifice to fulcrum thereon and then to open the inlet valve. Actuating mechanism tilts the lever acting at a point near the exhaust plug and there are means for opening the inlet valve located between the two ends of the lever at a point nearer to the said actuating mechanism than to the exhaust closure plug.

VIBRATION.

506,687. *Improvements relating to Hydraulic Vibration Dampers.* Avimo, Ltd., Rowbarton; Stevens, H. C. M., Lyndale, Galmington; Foster, F., Osborne Grove House, Haines Hill, Taunton, Somerset. Dated Dec. 30th, 1937. No. 36,074.

This arrangement is proposed for preventing vibration on the controls of aircraft. It consists of a cylinder filled with oil and a piston and piston rod. There is a fluid leak round the piston and another rod which can be used for imparting intentional motion to the piston by hand or otherwise. A fluid leak is produced by relative movement between this rod and the piston.

501,887. *Improvements in or relating to Rubber Surfaced Structural Elements.* International Latex Processes, Ltd., 10, Lefebvre Street, St. Peter Port, Guernsey, Channel Islands. Convention date (U.S.A.), Jan. 4th, 1938.

In order to reduce the transmission of vibration and sound waves in aircraft structures, the structural element is provided with a coating presenting a rough uneven outer surface of irregularly spaced protruding soft rubber particles comprising the *in situ* solids deposit of a latex composition. The soft rubber is intended to include products vulcanised with up to 8 per cent. of sulphur.

DR. ING. RUD. JAESCHKE: "FLUGZEUGBERECHNUNG" (Aeroplane Calculations). Vol. I., "*Grundlagen der Stroemungslehre und Flugmechanik*" (Elements of Aerodynamics and Aircraft Mechanics). 2nd Edit. 174 pages with 88 fig. and 21 num. tabl. Vol. II., "*Bearbeitung von Entwuerfen and Unterlagen fuer den Festigkeitsnachweis*" (Handling of Designs and Load Computation for Stressing). 202 pp., 64 fig. and 38 num. tabl. Munich and Berlin, 1939. Publ. by Verlag von R. Oldenbourg. Price of both vols. bound together R.M. 13.—.

This is a modern textbook which deals with the aerodynamic side of aeroplane design and which is mainly compiled for the instruction of engineering students. The hydrodynamic fundamentals of air flow are not included but the results are used.

The first volume gives practical aerodynamic calculations (induced drag, characteristics of aerofoil sections), mechanics of flight, performance and (static) stability calculations, all in a fairly elementary form.

The second volume appears to be somewhat disconnected. The first part is a general discussion of design problems including an interesting chapter dealing with unusual aircraft such as flapping wing aircraft, paddle wheel aircraft, tail-first aeroplanes, muscle-power flight, etc., and another gives characteristics of normal modern aeroplanes and the features of their lay-out. A second part discusses the actual design procedure of a project (with a far too short reference to flying qualities, especially to spinning). A third part deals with load assumptions (Example: Calculation of a biplane in fairly elaborate form) and with the calculation of the actual air forces acting upon the wings. In conclusion, methods are given for the calculation of the lift distribution across the span and along the chord of arbitrary wing systems, together with numerical examples. This is the only part which cannot be called elementary.

The book is certainly well written and instructive, the author being a lecturer in aeronautics. It does not deal with the theory, but uses only the results of it, thus providing the danger of insufficiently founded generalisations by students. Otherwise, students as well as aeronautical lecturers will find the book a useful one.

E. L. EATON: "WEATHER GUIDE FOR AIR PILOTS."
New York. 1939. Published by the Ronald Press Company. 74 pp., 9 Plates of Cloud Formations, 18 Figures. Price $2.—.

This concise manual is obviously compiled for the amateur pilot flying in the U.S.A., and complies with the modern standard of meteorology and weather forecasting. The six chapters of the book deal with the atmosphere in general, with the laws of atmospheric pressure distribution, air mass and weather front analysis and the information contained in synoptic weather charts; with hazards such as thunderstorms, ice accretion and fogs, with cloud formations, U.S.A. weather services and with climatic characteristics of the territory of the United States.

With regard to the formation of clear ice on aeroplane parts, the time limit of 6 minutes for getting rid of the ice ought to be taken with caution, as this time interval has been found to depend largely upon the speed of the aircraft in question and upon surface conditions of the parts concerned.

The book is a thoroughly practical one and should be helpful for pilots who, without being particularly interested in the science of meteorology, have need of some fundamental information as to facts and possibilities. Unfortunately, for English readers, the book will be of limited use, as it only refers to conditions and services in the U.S.A.

JAHRBUCH 1938 DER DEUTSCHEN LUFTFAHRTFORSCHUNG. (German Aeronautical Research Yearbook, 1938. In collaboration with the German Air Ministry and German Aeronautical Research Institute.)

Edited by the Central Office for Scientific Aeronautical Reports, Munich and Berlin. 1939. Published by Verlag R. Oldenbourg. 1,216 pp. with numerous figures, photographs and tables. Price R.M. 50.—.

The introductory section of this large volume contains business reports of German aeronautical associations and research institutes. The other parts, dealing respectively with airframes, engines and equipment, have no less than 152 technical and scientific reports. Some of these appear for the first time, others are reprints from " Luftfahrtforschung," the L.U.F.O. or D.V.L. Yearbooks, or other periodicals.

Among those reports from the L.U.F.O. Yearbook which are published here, the following deserve mention:—

" Two-dimensional potential flow about thick aerofoils of a given shape " (Keune), evolving a method for the calculation of airflow in the vicinity of a given aerofoil, taking into consideration the thickness of the aerofoil.

" Generalisation of Birnbaum's theory for potential flow for aerofoils of moderate thickness " (Gebelein), giving a new approximate method deduced from Birnbaum's exact solution.

" Calculation of the pressure distribution for Karman-Trefftz aerofoils at high lift coefficients " (Keune and Fluegge-Lotz).

" Calculation of an aerofoil section for a given pressure distribution " (Mangler).

" Theoretical calculation of profile drag " (Pretch), with the assumption that the breakaway of the friction layer can be neglected.

" Results of calculated pressure distributions over any aerofoil section " (Kochanowsky). A comparison with wind tunnel measurements shows good agreement.

" Pressure distribution on wings, with backward airflow " (Neumann). Wind tunnel tests with two wings, in order to define the air loads acting on rudder with picketed aeroplanes.

" Method for the calculation of lift distribution over wings having flaps and ailerons " (Kolscher).

" Comprehensive report concerning down-wash measurements with and without slipstream " (Fluegge-Lotz and Kuechemann). This comparative study of wind tunnel tests, made chiefly in this country, indicates that no theoretical treatment has yet been deduced for the case of a rotating airscrew, while with engine on, the " efficiency factor " of the tail plane is of major importance.

" Flying experiments and calculations with regard to air loads imposed by elevator action " (Kaul and Lindemann), describes the results of tests with a BFW.M. 29 monoplane equipped with elevator and tail plane.

Two very valuable reports refer to the influence of the sense of airscrew rotation upon the longitudinal stability of twin-engined aeroplanes. The first report, contributed by Stiess of the Dornier Works, gives the results of comparative flight measurements on a Do.17 bomber equipped with twin engines, with three different combinations of airscrew rotation. The results show that stability is considerably improved with opposite rotating airscrews, the starboard being a right-hand tractor and the port a left-hand tractor. With this combination, the position of the centre of gravity for neutral stability is farther back, giving more space for useful load. Wind tunnel tests on a model of another make of twin-engined monoplane (article by Seifert) are in complete agreement.

The problems of static longitudinal stability are discussed by von Doepp, the aerodynamics expert of the Junkers works. He refers to the influence of fuselage, nacelles, Reynolds number and Mach number upon the position of the aerodynamic centre, and also to the unbalancing effect of the rotating tractor airscrew.

" Unstable flying motions " (Hesselbach). General consideration of the mechanics of dynamic longitudinal stability.

" Yawing and rolling oscillations of an aeroplane " (Bartsch). An evaluation of the yawing stability theory, dealing with problems concerning the degree of aerodynamic balancing of ailerons and rudders.

" Further tests with regard to wing flutter " (Voigt).

" Influence of certain design features on flutter and the aperiodic buffeting of wings, with and without ailerons " (Leiss).

Problems of load statistics are dealt with in a report by Kaul concerning the endurance strength of aeroplane wing structures.

" Maxima and frequencies of gust loads occurring on commercial aeroplanes " (Freise).

" Performance measurements of a Focke Wulf Stoesser FW. 56 with the airscrew removed " (Spilger). This fairly heavily loaded single-seater fighter trainer, flown by Miss Hanna Reitsch, was towed by another aeroplane, measurements being taken during the glides. The best gliding angle observed (radiator flap open) was 1/11.6 at a C_L of 0.85.

" Starting methods on steep slopes " (Isermann and Beck), using runways leading down a hill of 35° gradient.

" Air brakes for use in dives of aeroplanes and sail planes " (Jacobs and Wanner). The terminal velocity nose-dive speed of a FW. 56 Stoesser (flown by Miss H. Reitsch) could be reduced from 305 to 205 m.p.h., without any change in the flying behaviour.

" Performance tests with sail planes " (Spilger).

" Meteorological aspects of soaring flights in the Alps " (Maletzke).

The following three articles refer to seaplanes and flying boats:—

" Influence of hull shapes and shock absorbers on alighting shock " (Sydow).

" Load assumptions, derived from experiments with floats and boats made during commercial air traffic " (Langheinrich), in which it is stated that the Dornier Wal flying boats are still considered the most seaworthy in the world.

" Strength tests with floats " (Matthæs).

The next section deals with airscrews, under the headings:—

" Mechanical limits of the static thrust obtainable " (Betz).

" Systematic wind tunnel tests with a series of model airscrews " (Dirksen).

" Vibrational loads and endurance strength of electron airscrews " (Luerenbaum).

Centrifugal vibrations of airscrew blades which are universally hinged at the hub " (Havers and Meyer).

" Design problems of the wide blade airscrew " (Hoffmann).

Strength and constructional problems are the subject of the following articles:—

" The crippling of two-dimensional tension field beams " (Limpert).

" The use of the energy method for stability problems " (Marguerre).

" Influence of modifications in stiffness on the flow of forces in statically indeterminate wing systems " (Koeller).

" The distribution of forces on multispar wing systems with certain members removed " (Ebner and Koeller).

" Calculation of the stresses in ring stiffeners in cylindrical monocoques on which large local forces are acting " (Kalisch).

" The stressing and determination of the dimensions of wooden box and I-spars with the help of nomograms " (von Guerard).

" Monocoque construction at the Dornier works " (Petzold), giving a description of the split construction methods used for stressed skin components.

" Collaboration between designer and production manager " (Ritter), with reference to experience gained from production in the Junkers works.

" Monocoque construction with longitudinal panels " (Rethel). Discussion of a patented method of construction for fuselages.

" Design of welded components " (Rethel), with reference to experience gained in the Araldo works.

The next section, dealing with materials, contains the following :—

" The influence of copper, magnesium and silicon contents on the properties of aluminium-copper-magnesium alloys " (Siebel).

" Plating with pure aluminium " (Brenner).

" Notch effect under continued reversal stress, and the influence of cold working upon endurance strength " (Fischer).

" Endurance strength properties of magnesium alloys, with special reference to the effect of notching " (Buchmann).

" Dynamic strength of light alloys at low temperatures " (Bungardt).

" Spot welding of light alloys " (Reichel). Experience gained by the Araldo works indicates that the A.E.G. welding machine is capable of replacing riveting with aluminium-magnesium and aluminium sheets, but that thick electron and Alclad sheets still give rise to difficulties. A monocoque type fuselage made from M.G.7 alloy for a fighter has been welded and flown satisfactorily.

" Synthetic materials and their use " (Leysieffer).

" New research work concerning the use of plastics adaptable to hardening " (Kuech).

" Synthetic ' Buna ' rubber " (Konrad).

A final section on the technique of measurements contains reports on: compressibility influences on Prandtl pressure tubes; the Dornier air log; disturbed zones on wings of monoplanes; flight tests with the Raethjen Kino Theodolite (showing the considerable influence of the airscrew on the shape of the polar curve); a piezo-electric accelerometer.

The second part of the volume is devoted to engine reports, covering the following subjects: test benches for altitude flying research; altitude performance; temperature flight test; compression ignition engines; gas flow in cylinders and manifolds; spray formation under fuel injection; optimum cylinder sizes with regard to power output and heat distribution; piston and piston ring development; installation problems; research work with bearings; valve springs and crankshaft vibrations; axial blowers (by A. Betz, stating that such blowers have a higher efficiency and simpler construction than radial ones, but suffer from length and from a narrower range of high efficiencies); multi-stage blowers; blower drives; exhaust turbine driven blowers with internal cooling of the blades; heat dissipation from a wing section; cooling problems in altitude flying; research work with radiators; engine materials having suitable strength properties at high temperatures; fuel research.

The reports contained in the third part deal with :—

Progress in instruments; electrical installations on board aeroplanes; earphones used in aircraft; noise reduction; wireless and direction-finding apparatus; photographic equipment; medical research work (*e.g.*, altitude effects and the influence of accelerations on the human body and mind, where it is stated that for fighter pilots the customary English breakfast is preferable to the continental habit).

Like the 1937 yearbook, this volume forms a complete collection of the aeronautical technical work published or released for publication during the year. All those interested in technical progress who are able to read German will find the present yearbook as indispensable as its predecessor. Print and make-up are far better than those of the periodical " Luftfahrtforschung," from which so many of its reports are drawn.

Il Volo in Italia.

Edited by Federigo Valli and Antonio Foschini. Editoriale Aeronautica, Rome. 1939. Price Lire 10 (limp cardboard cover) or Lire 20 (bound).

Like all good anthologies this book contains brilliant cameos in writing, each complete in itself, but, unlike most, it presents them in an orderly sequence: Myth

and Legend; Early Experiments; the Conquest of the Air; the World War; Technical Progress; Aviation to-day; a final section being devoted to purely literary impressions of flight.

Only Latin genius could contrive a book so readable for a layman and yet so useful to an expert. Furthermore, the wealth of illustrations is a joy, even to those who do not read Italian. Particularly interesting are the facsimiles of Leonardo da Vinci's writings on flight (pp. 51-61), while an unusual feature is the reproduction of line-drawings by airman artists. Among these, De Pinedo's sketch of Del Prete taking a sight has an intimate quality, to which poignancy is added by the fact that both men are now dead. The new art of Aero-Painting, so strongly developed in Italy, is represented by a number of pictures, of which " Night Patrol " is perhaps the most beautiful, and " Il Duce " the most striking.

No one who contemplates writing a history of aviation, or who is interested in flying from a literary and pictorial standpoint can afford to miss this anthology.

LOTHAR AHRENS: " TASCHENWOERTERBUCH FLUGWESEN, FUENFSPRACHIG." (Aeronautical Pocket Dictionary in Five Languages, German—English—French—Italian—Spanish.)

Berlin. 1939. Published by V. D. I. Verlag G.m.b.H. 576 pp. Price R.M. 12.—.

Every expression in this dictionary is accompanied by a reference number so that it might also be used as a code. It is a practical work and the 3660 different aeronautical expressions are grouped in chapters in accordance with the branch of aeronautics to which they refer. These chapters deal with aircraft categories, equipment, registration, handling of aircraft, model aeronautics, industrial expressions, service aviation, aid raid precaution and general aeronautical matters. For the aeronautical engineer in the drawing office and in the workshop the range of technical expressions is not big enough, and certainly not up to the standard of the " Schlomann-Oldenbourg." The second part of the dictionary is formed by five alphabetical indices, one for each language; giving the reference numbers mentioned above.

This dictionary seems to be carefully compiled, apart from a few minor items, such as, for instance, " avion aile " (instead of " aile volante," for flying wing aeroplane), " wire cross bracing " (diagonal bracing), " underpowered motor glider " (sail plane with auxiliary engine), " formula " (type or version), etc.

For use while travelling abroad in connection with aeronautics, the dictionary can be recommended. Judging by the size of this useful " pocket " dictionary it seems that German pockets have grown pretty large in recent times.

PROF. DR. W. SCHLINK: " TECHNISCHE STATIK. EIN LEHRBUCH ZUR EINFUEHRUNG INS TECHNISCHE DENKEN." (Technical Statics. A Treatise into Technical Reasoning.) With collaboration by H. Dietz.

Berlin. 1939. Published by Verlag von Julius Springer. 386 pp. with 463 figures. Price R.M. 27.60.

This book originates from lectures the author has held as a university teacher for engineering students at Darmstadt. It deals with the statics of rigid bodies as an introduction into higher statics. A special section is devoted to the treatment of three-dimensional problems.

The first part deals with central forces, the following ones with dispersed forces acting in the same plane, with two-dimensional frame systems, with forces acting in space and with three dimensional structures. The elementary theory of statically indeterminate structures is included. A number of the examples treated refer to structural problems of aeronautics.

This textbook appears to be written in a very clear and careful manner, and it is well suited for home studies.

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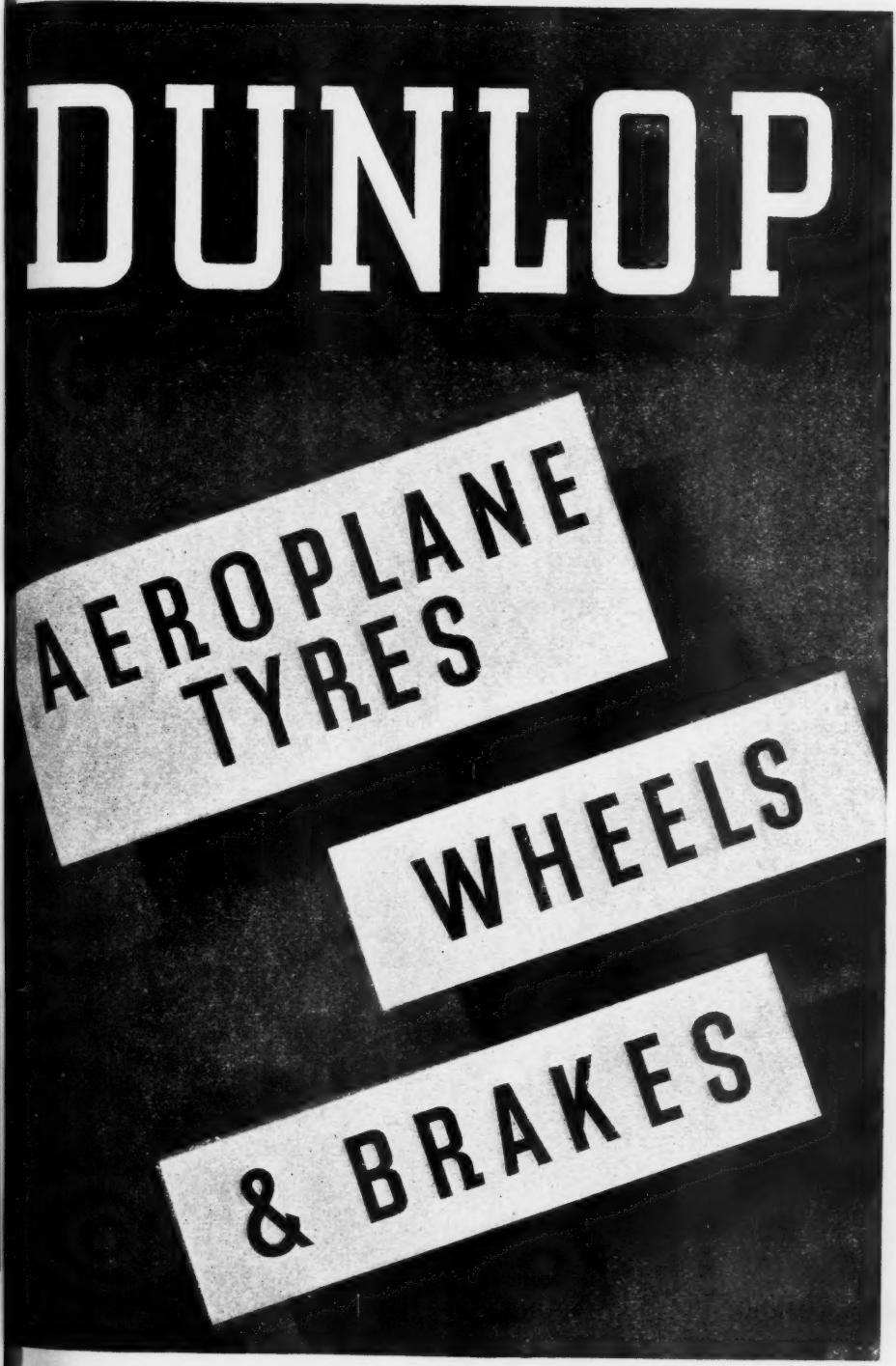
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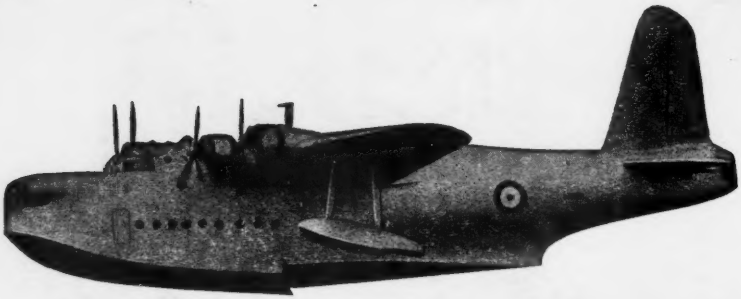

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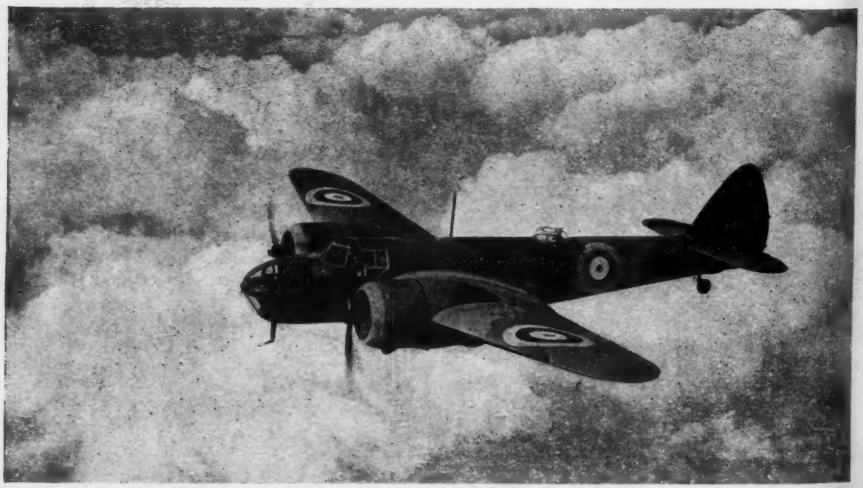

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MONTHLY NOTICES

OCTOBER, 1939

Presidential Address.

The President, Mr. A. H. R. Fedden, who was to have given his Presidential address before the Society at the opening of the Lecture Session in October, has had, to his deep regret, to cancel his address.

A personal letter from the President has been sent to every member and will be printed in the November issue of the Journal.

Society's Arrangements.

The outbreak of war makes it necessary, during a re-organisation period in every branch of life, for the Society to carry out certain re-adjustments of its activities. A large proportion of members of the Society are engaged in work connected with the war, and have been scattered over the country, so that it will not be possible for them to meet easily.

It is not possible for the Society to legislate far ahead at the time this issue of the Journal goes to press, and such arrangements as are now announced are temporary ones to fit in with the actual situation.

Every effort is being made to carry on as much of the normal activities of the Society as possible with a heavily depleted staff.

Meetings.

The lectures arranged for the present session have been postponed. They will be resumed at the earliest possible moment, dependant upon the possibility of members being able to attend and the release of such information by the authorities which will make the lectures worth while.

The 1940 Air Conference, arranged to be held at Stratford-on-Avon has been postponed.

Journal.

The Journal will continue to be published monthly as usual. During the period of the war the Monthly Notices will be incorporated in the Journal and the green leaflet notices suspended.

Headquarters facilities.

The headquarters of the Society, No. 4, Hamilton Place, will be open every day, except Saturdays. The hours of opening will depend upon daylight. In any case the office will close not later than one clear hour before the black-out period begins.

Every effort will be made to give technical information as in the past, but it will not be possible for members to borrow books for a longer period than a week. Only one book may be borrowed at a time and those who borrow books must return them by *registered* post. Where possible information which a member

knows is in a book should be asked for rather than the book. The supply of technical information during the war period is even more important than in peace time, and it is hoped to publish papers and abstracts at least as fully as in normal times. Books may not be borrowed and kept by students for the purpose of studying for examinations.

List of Members.

Owing to the many changes of address of members of the Society, the member's list will not be published in January 1940 but later in the year as circumstances permit.

Emergency Address.

All communications to the Society may be sent direct to headquarters, No. 4, Hamilton Place, London, W.1, or to its country address, Brook House, Old School Lane, Brockham, Surrey. (Telephone Betchworth 189.) Urgent communications to the latter address will be dealt with every day (including Saturdays). Full arrangements have been made to carry on the necessary work of the Society at Brockham if it becomes impossible to continue in London. All of the historical records of the Society itself and a number of valuable books have been moved into the country.

Central Register.

Those members of the Society who have received their Central Register cards and have not yet returned them should do so immediately. It is vitally necessary to keep them going up to date and any change of address should be immediately notified to the Secretary, who is a member of the Central Register and will keep the Ministry of Labour informed. Members should also inform the Secretary of any change of employer or of any additional qualifications they may obtain since sending in their cards.

The Central Register exists in general terms for the supply of and placing of qualified technical persons in positions most suited for their qualifications. Any communications with reference to the Register should be sent to the Secretary.

Any member of the Society with technical experience, who is out of a post, should write the Secretary immediately, giving full particulars of his qualifications.

Staff.

The headquarters staff of the Society has been considerably reduced, largely owing to members taking up various forms of war work. I make an appeal, therefore, to all members, to make allowances for any unavoidable delays which may occur during the next few weeks.

President 1939—1940.

Mr. A. H. R. Fedden, M.B.E., D.Sc., M.I.A.E., M.I.Mech.E., M.S.A.E., F.R.Ae.S., the President for 1938-1939, will commence his second term of office on October 1st.

Council Meeting.

A meeting of the Council was held in the Society's Offices on Wednesday, September 13th, 1939, when the following members of Council were present:—

Mr. A. H. R. Fedden (President) in the Chair; Captain P. D. Acland, Professor L. Bairstow, Mr. Griffith Brewer (Vice-President), Mr. S. Camm, Mr. A. Gouge, Major D. H. Kennedy (Honorary Treasurer), Professor F. T. Hill, Mr. F. Handley Page, Lord Sempill, Mr. F. M. Thomas, Mr. C. C. Walker, Dr. H. C. Watts, Mr. L. A. Wingfield (Solicitor), Mr. R. T. Youngman.

In Attendance: The Secretary and Mr. Norman Smith (Honorary Accountant).

Apologies for absence were received from Lt.-Col. W. Lockwood Marsh, Major

B. W. Shilson, Mr. W. C. Devereux, Air Vice-Marshal R. M. Hill (Vice-President) and Professor A. J. Sutton Pippard.

Among the business discussed was the following:—Trust Funds; Finance: General Policy of the Society during the War period; Postponement of Lectures and other functions; Election of new members; Meetings of Council and Committees.

Election of Members.

The following new members have been elected:—

Fellows.—Edgar Alfred Allcut (from Associate Fellow), Arthur Joseph Hughes (from Associate Fellow), H. John Stieger (from Associate Fellow), Percy Brooksbank Walker (from Associate Fellow).

Associate Fellows.—Paul Emory Clift, Roland Claude Cross, Lancer Dudley Vibart Edwards, Philip Francis Everitt, Archibald Graham Forsyth, Robert Ernest Hardingham, Geoffrey Moffat Hellings, Benny Lockspeiser, Frank John Murdoch (from Companion), Arthur Drummond William Pimm (from Graduate), John Cecil Kelly Rogers, Edward Smyth, Stanley Joseph Smyth, Robert James Spearman (from Graduate).

Associates.—Graham Brook Bell, John William Sefton Brancker, John David Cunningham, Kenneth Moreton Frewin, John Burgoyne Joyce, Shashi Majumdar, Henry Campbell Russell, Howard Charles Sheath, Joseph Carey Crabtree Taylor.

Graduates.—Brian Hugh Muirhead Buck (from Student), John Owen Parker Dibbs, William Patrick Ingram Fillingham (from Student), John Hawke Horsfield (from Student), William James Muskett, Thomas Henry Redding, Philip George Richardson, Norman Wilfred Savage.

Students.—Arthur Lionel Benns, Harold Colin Black, John Morrison Boulter, Ronald French Carter, Ronald Arthur Cashel, Vivian James Chalwin, Peter Smithard Champion-Jones, James Alfred Collins, William George Coxon, Eric Crowe, Frank Cyril Dedman, Douglas Fernley Denbow, Joseph Raymond Dennis, Ronald Dimberline, Edward Reed Douglass, Harold Frederick Drummond, Arthur William Edwards, Stanley Charles Evans, Walter Fairey, Donald Albert Flint, Reginald Thomas Folley, Douglas Foster, Darrell Ivor Gale, Trevor Douglas Buchanan Garrett, Edmund Frank John Gericke, Alfred Kenneth Germain, John Ernest Haines, William Henry Harris, William Ronald Hasler, William Samuel Haynes, William Norman Helsby, Robert Walter Hern, Dennis Hill, Ronald Frank Hitchcock, James Inward, Henry Alfred Jackman, Peter Edward James Jenkins, Eric John Jennings, Norman G. Jones, Oliver Keene, William Alfred Clifford Kendall, James Henry Kent, Ronald Lasslett-Carter, Julian Leslie, Kelvin Oliver Lockyear, Michael John McCluskey, John Frederick McGowan, Joseph Mackereth, Cyril Roy Major, Reginald Wilfred Manning, Gerald James Matthews, John Meaking, John Edward Millis, Robert John Millson, Edward Frank Mitchell, Patrick James Moore, Richard Ronald Moore, John Blair Willis Murray, Leslie Raymond Nash, Arthur Cyril Needham, Bruce Allan Noble, Denys Norton, Arthur William Nunn, Ian Bruce Ogilvie, Edward Harold Orchard, Norman Leslie Cyril Parfitt, Roland Park, Cyril Hugh Lynn Parry, Norman Christian Pedersen, Cyril James William Perkins, Kenneth Arthur John Pettet, Kenneth Walter Thomas Pugh, Theodore Grimmer Raynham, John Tudor Reynolds, Leslie William Richardson, John

Alexander Ross, John James Roy, Anthony Derek Ruscoe, Gilbert Frank Satchwell, Kenneth John Smedley, Walter Roy Stapleford, Eric George Bond Starling, John Anderson Steed, John Stephens, Ernest Evelyn Stevens, Cyril John Tapsell, Ian Straughan Thomson, Kenneth Frank Venn, Wilfred George John Wallace, Charles Joseph Nicholas Watkin, Thomas Whittaker, Richard Ivor George Whittington, David Howard Williams, Cyril Stanley Wyatt.

Companions.—James William Carr, Arthur George Berkeley Sutherland, Axel Charles Wickman, Jack Noel Williams.

Associate Fellowship and Associate Membership Examinations.

The next Examinations will be held on December 20th, 21st and 22nd. Further particulars will be sent later to Candidates who have already entered.

Graduates' and Students' Section.

The programme of lectures and visits arranged for the Graduates' and Students' have been postponed for the time being.

Additions to Library.

Aeronautical Research Committee: Reports and Memoranda:—

No. 1860. Diffusion of Concentrated Loads into Monocoque Structures. III. General Considerations, with particular reference to Bending Load Distributions. By H. L. Cox. 1938. 2/-.

No. 1862. Diffusion of Load in Sheet-Stringer Structures having a Tapered Centre Stringer. By H. E. Smith. 1938. 2/.

National Advisory Committee for Aeronautics: Technical Memoranda:—

No. 869. The Conversion of Energy in a Radiator. By A. Weise. (From Hauptversammlung 1937 der Lilienthal-Gesellschaft.)

No. 870. Behavior of a Plate Strip under Shear and Compressive Stresses beyond the Buckling Limit. By A. Kromm and K. Marguerre. (From Luftfahrtforschung, Vol. 14, No. 12, December 1937.)

No. 871. Performance of Rotating-Wing Aircraft. By K. Hohenemser. (From Ingenieur-Archiv, Vol. 8, December 1937.)

No. 872. The present status of Airship Construction, especially of Airship-Framing Construction. By Hans Ebner. (From Z.F.M., Vol. 24, Nos. 11 and 12, June 6 and 28, 1933.)

No. 873. Experimental Study of Ignition by Hot Spot in Internal Combustion Engines. By Max Serruys. (From Ministère de l'Air, P.Sc.T. No. 115.)

No. 874. Effect of Propeller Slipstream on Wing and Tail. By J. Stüper. (From Luftfahrtforschung, Vol. 15, April 6, 1938.)

No. 875. Heat-Stressed Structural Components in Combustion-Engine Design. By Otto Kraemer. (From Zeitschrift des VDI, Vol. 82, March 12, 1938.)

No. 876. Investigations on the Downwash behind a Tapered Wing with Fuselage and Propeller. By H. Muttray. (From Luftfahrtforschung, Vol. 15, March 20, 1938.)

No. 877. Wind-Tunnel Investigations of Flexual-Torsional Wing Flutter. By H. Voigt. (From Luftfahrtforschung, Vol. 14, Sept. 20, 1937.)

No. 878. The Twisting of Thin-Walled, Stiffened Circular Cylinders. By E. Schapitz. (From Lilienthal Gesellschaft Jahrbuch, 1936.)

No. 879. Static Longitudinal Stability and Longitudinal Control of Autogiro Rotors. By M. Schrenk. (From Luftfahrtforschung, Vol. 15, July 6, 1938.)

No. 880. The Effective Width of Curved Sheet after Buckling. By W. A. Wenzek. (From Luftfahrtforschung, Vol. 15, July 6, 1938.)

No. 881. Application and Testing of Transparent Plastics used in Aeroplane Construction. By K. Riechers and J. Olms. (From Luftwissen, Vol. V, June 1938.)

No. 882. Modern Manufacturing Equipment of the Ernst Heinkel Airplane Works. By A. Thormann and H. Jockisch. (From Luftfahrtforschung, Vol. XV, January 1938.)

No. 883. Distribution of Temperatures over an Airplane Wing with reference to the Phenomena of Ice Formation. By Edmond Brun. (From Ministère de l'Air, P.Sc.T. No. 119.)

No. 884. Calculation of the Induced Efficiency of heavily loaded Propellers having an Infinite Number of Blades. By F. Lösch.
The Induced Efficiency of Optimum Propellers having a Finite Number of Blades. By K. N. Kramer.
Prospects of Propeller Drive for High Flying Speeds. By G. Bock and R. Nikodemus. (From Luftfahrtforschung, Vol. 15, July 1938.)

No. 885. Meteorological-Physical Limitations of Icing in the Atmosphere. By W. Findeisen. (From Hauptversammlung der Lilienthal-Gesellschaft, October 1938.)

No. 886. Theory of Two-Dimensional Potential Flow about arbitrary Wing Sections. By H. Gebelein. (From Ingenieur-Archiv, Vol. IX, June 1938.)

No. 887. Comparison of Theory with Experiment in the Phenomenon of Wing Flutter. By P. Cicala. (From Aerotecnica, Vol. XVIII, April 1938.)

No. 888. Ice Formation on Wings. By L. Ritz. (From Hauptversammlung der Lilienthal-Gesellschaft, October, 1938.)

No. 889. Investigation of the Lift Distribution over the separate Wings of a Biplane. By D. Küchemann. (Luftfahrtforschung, Vol. XV, October, 1938.)

No. 890. Experiments on a Slotted Wing. By P. Ruden. (From Jahrbuch der Luftfahrtforschung, 1937.)

No. 891. Theoretical and Experimental Study of Ignition Lag and Engine Knock. By Fritz A. F. Schmidt. (From VDI-Forschungsheft 392.)

No. 892. Investigations and Tests in the Towing Basin at Guidonia. By C. Cremona. (From Hauptversammlung der Lilienthal-Gesellschaft, October, 1938.)

No. 893. Contribution to the Theory of the Heated Duct Radiator. By H. Winter. (Luftfahrtforschung, Vol. XV, October 1938.)

No. 894. The Way to increased Airplane Engine Power. By Eugen Vohrer. (From Luftwissen, Vol. 5, October 1938.)

No. 895. The Power of Aircraft Engines at Altitude. By Paolo Ragazzi. (From Hauptversammlung der Lilienthal-Gesellschaft, Oct. 1938.)

No. 896. The Drag of Airplane Radiators with special reference to Air Heating. (Comparison of Theory and Experiment.) By B. Göthert. (From Luftfahrtforschung, Vol. XV, September 1938.)

No. 897. Airfoil Theory at Supersonic Speed. By H. Schlichting. (From Luftfahrtforschung, Jahrbuch 1937.)

No. 898. The Limit of Stability of a Curved Plate Strip under Shear and Axial Stresses. By A. Kromm. (From Luftfahrtforschung, Vol. XV, October 1938.)

No. 899. The Hydrodynamic Theory of Detonation. By Heinz Langweiler. (From Z.T.P., Vol. 19, No. 9, 1938.)

No. 900. The Effect of the Masses of the Controls on the Longitudinal Stability with Free Elevator. By Rudolph Schmidt. (From Luftfahrtforschung, Vol. XVI, January 1939.)

U.S. Works Progress Administration: Bibliography of Aeronautics:—

Part 39: Stress Analysis.

Part 41: Comfort in Aircraft.

Part 45: Wind Tunnels and Laboratories.

Air Ministry Publications (all obtainable from H.M.S.O. at prices stated):—

A.P. 1354. Air Photography. (1936.) 3/-.

A.P. 1699. Meteorology for Aviators. By R. C. Sutcliffe. 1939. 7/6.

A.P. 1692. The Civil Aviation Communications Handbook. 1939. 1/-.

A.P. 968. Regulations for the Auxiliary Air Force, the A.A.F. Reserve and County Associations. 1939. 3/6.

A.P. 1208. Airworthiness Handbook for Civil Aircraft, Vol. II (Inspection Section). 1938. 7/6.

Rg. 67. Handbook for Wireless Operators. 1939. 9d.

Cmd. 6004. Civil Air Transport Services: European Services (Agreement with Imperial Airways.) 1939. 1d.

Cmd. 6005. Civil Air Transport Services: European Services (Agreement with British Airways). 1939. 1d.

Cmd. 6006. Air Raid Shelters: Report of the Lord Privy Seal's Conference.

A.M. Pamphlet 13. Conditions of Entry and Service on Short Service Commissions in the General Duties Branch of the Royal Air Force. 1939. 3d.

A.M. Pamphlet 17. Conditions for Entry into the Stores Branch of the Royal Air Force on permanent Commissions. 1935. 2d.

A.R.P. Handbook No. 9. Incendiary Bombs and Fire Precautions. 1939. 6d.

Notices to Aircraft Owners and Ground Engineers, 1920—1938. (1939.) 2/6.

Government Publications: Consolidated List for 1938. (1939.) 1/-.

Papers set at Examination for Civil Aircraft Navigator's Licence (1st Class), April 1938. (1938.) 2/-.

Papers set at Examination for Civil Aircraft Navigator's Licence (2nd Class), April 1938. (1938.) 1/6.

Pamphlet on Shelter from Air Attack. (Home Office A.R.P. Dept.) 1939. 2d.

Air Raid Precautions for Government Contractors. (Issued by Admiralty, War Office and Air Ministry.) 1939. 4d.

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Cmd. 4654. Memorandum by the Secretary of State for Air on the Report of the Committee on Control of Private Flying and other Civil Aviation questions, etc. (Gorell Report.) 1934. 1/3.

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University of Toronto: Faculty of Applied Science and Engineering School: Bulletin No. 154. An Automatic Frequency Regulator. By H. W. Price and C. Kent. University of Toronto Press. 1938.

India Meteorological Department:—

Scientific Notes, Vol. VII, No. 80. Normal Monthly Percentage Frequencies of Surface and Upper Winds (Afternoon) up to 3 km. in India, Burma and Persian Gulf. Manager of Publications, Delhi. 5/6.

The Aeroplane Speaks. (Sixth Edition.) By H. Barber. McBride, Nast & Co., 1918.

Aerostation. (Article extracted from a Dictionary—probably "Encyclopædia Metropolitana"—and bound in plain cardboard cover: approx. 1845.)

Air Challenge and the Locusts. By Hugh W. Bayly. John Lane (The Bodley Head), 1939. 7/6.

Birmal Technical Data. (Looseleaf Book.) Birmingham Aluminium Casting Co., Ltd. 1935.

A Dictionary of the Wonders of Art. Published by T. Hurst, London. 1803. 10/6.

First Book of the Spheare. By M. Blundeville. John Windet, London. 1594. (Incomplete copy, much damaged.)

Historia de la Aeronautica en España, Portugal, Paises Hispano-Americanos y Filipinos. By P. Vindel and G. D. Arquer. (With Prologue by Emilio Herrera.) Pedro Vindel, Madrid. 1930. (No. 139 of limited edition of 250 copies.)

Isoazimuthal Lines of Position at Sea and in the Air. (Uniform and Universal Solutions.) By Captain Radler de Aquino. Imprensa Naval, Rio de Janeiro, 1939.

Lost Flights of Gustave Whitehead. By Stella Randolph. Places, Inc., Washington. 1937. 10/-.

Magnesite: its Preparation and Technical Uses. The Indian Magnesite Industry. Two Papers by H. H. Dains, reprinted from Journal of the Society of Chemical Industry, 1909 and 1912.

Magnesium Alloys (with special reference to Elektron). British Elektron Patent Owners. 1934.

La Navigation Aérienne par Vent Variable. By P. Theodorides. Imprimeria Nationala, Bucharest, 1938.

The Oil Engine Manual. By D. S. D. Williams and J. Millar Smith. English Universities Press, 1939. 5/-.

Principles of Rotary Aircraft. Alexander Klemin. Reprint from Journal of Franklin Institute, 1939. $1.00.

Proceedings of Rotating Wing Aircraft Meeting at Franklin Institute, October, 1938. (Stencil.) Institute of Aeronautical Sciences, U.S.A. $2.00.

Reichsluftkursbuch, August 1939. (Official Airways Timetable.) Deutsche Lufthansa. 2/-.

Report on Occupancy Tests of Air-Raid Shelters for Factory Workers. Issued by J. and E. Hall, Ltd. (Dartford), printed by H. K. Lewis and Co., W.C.1. 2/-.

Rubber in Automobiles. By Colin Macbeth. (Advance Proof of Lecture read before the Automobile Conference, November 9th, 1937.)

Span. (Second Annual Lecture.) Professor F. W. Lanchester. (Read before the Manchester Association of Engineers, November 9th, 1938.)

Tests on Model Propellers. By J. Lawrence Hodgson. (Paper read before the Institute of Automobile Engineers, 1917.)

Also the following books, bequeathed from the Library of the late Mr. R. L. Howard-Flanders:—

Complete Book of Aviation. By Squadron Leader C. G. Burge. Sir Isaac Pitman and Sons, 1935. 15/-.

Technical Report of the Advisory Committee for Aeronautics for the Year 1912—13. H.M.S.O. 10/-.

The Air Annual of the British Empire, 1930. By Squadron Leader C. G. Burge. Gale and Polden, Ltd. 21/-.

Applied Aerodynamics. By Professor Leonard Bairstow. Longman's, Green and Co., 1920. 32/-.

The Aero. (Magazine.) Bound Volume (July 13—November 13, 1909.)

The Aeroplane. (Magazine.) 1915. (2 Volumes.)

Flight. (Magazine.) Bound Volume (March 6—November 13, 1909.)

Jane's All the World's Aircraft. Edited by C. G. Grey. Sampson Low, Marston and Co., 1929 and 1930.

Aeronautics. (Magazine.) Unbound Copies: October 23rd, 1919, and April 29th, 1920.

J. Laurence Pritchard, *Secretary and Editor.*

The 648th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

THE 1939 (27TH) WILBUR WRIGHT MEMORIAL LECTURE.

The 27th Wilbur Wright Memorial Lecture was delivered at a meeting of the Society which was held at the Institution of Mechanical Engineers, London, on Thursday, May 25th, by kind permission of the Council of the Institution.

In the Chair, Mr. A. H. R. Fedden, President of the Society.

THE PRESIDENT: Before calling upon Dr. George W. Lewis to give the Wilbur Wright lecture he had the pleasant duty of presenting the Awards and Medals for the past year.

These were then handed to the awardees as follows:—

SILVER MEDAL

To Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S., for his work on the Mayo Composite Machine leading to an advance in aeronautical design.

The Silver Medal is awarded annually, at the discretion of the Council for some advance in aeronautical design.

TAYLOR GOLD MEDAL.

To Squadron Leader H. P. Fraser, A.F.C., B.A., A.F.R.Ae.S., R.A.F., for his paper on "High Wing Loading and Some of Its Problems from the Pilot's Point of View."

The Taylor Gold Medal is awarded annually, at the discretion of the Council, for the most valuable paper submitted or read during the previous session.

WAKEFIELD GOLD MEDAL.

To Mr. Leslie L. Irvin for his lifelong work on parachute design which has led towards safety in flying.

The Wakefield Gold Medal is awarded annually to the designer of any invention or apparatus tending towards safety in flying.

BUSK MEMORIAL PRIZE.

To Squadron Leader G. M. Buxton, R.A.F., for his paper on "The Development of Sailplanes" and to Mr. H. F. Vessey, A.F.R.Ae.S., for his paper on "Effect of Wing Loading on the Design of Modern Aircraft with Particular Regard to Take-off Problems."

The Edward Busk Memorial Prize is offered annually for the best paper received by the Society on some subject of a technical nature in connection with aeroplanes or seaplanes.

PILCHER MEMORIAL PRIZE.

To Mr. H. E. J. Rochefort, Wh.Sch., A.C.G.I., D.I.C., for his paper on "The Theory and Practice of Stressed Skin Construction for Aeroplanes."

The Pilcher Memorial Prize is offered annually for the best paper by a student on heavier-than-air craft.

USBORNE MEMORIAL PRIZE.

To Mr. P. H. Rayner, B.Sc., for his paper on "Notes on Aero Engine Research."

Awarded annually for the best paper by a student on Aero Engines.

MAJOR BADEN-POWELL MEMORIAL PRIZE.

To Mr. R. T. Wall.

The Major Baden-Powell Memorial Prize is awarded in May and December of each year to the student obtaining the highest number of marks in the Society's Associate Fellowship and Associate Membership examinations.

THE SECRETARY: He called upon Dr. Lewis for a special reason which, he said, Dr. Lewis himself would explain.

DR. GEORGE W. LEWIS: He had the very pleasant duty to perform of presenting a medal to the President of the Royal Aeronautical Society. When Daniel Guggenheim became a generous patron of aviation in the United States he had no intention that a medal would be awarded in his name. He had done a very great deal for aeronautical science in the United States where he had donated about 4,000,000 dollars for the purpose. He had also helped other worthy causes such as the Royal Aeronautical Society in England, the Aero Club in Germany and the Aero Club in France, and after four years the Trustees of the Fund decided that it was proper that a medal should be awarded in Daniel Guggenheim's name. It was the highest honour which the Trustees could award to anyone in the United States or in any other country, and for the year 1938 the Medal Board had awarded the medal to Mr. Fedden, the President of the Royal Aeronautical Society (loud applause). It was a very great pleasure to him, as President of the Daniel Guggenheim Fund, and also as President of the Institute of Aeronautical Sciences to be privileged to hand the Medal and the Certificate of Award to Mr. Fedden (loud applause).

MAJOR LESTER GARDNER (U.S.A.): About a year ago a letter was received in the United States from New Zealand saying that they wished to establish an award and asked that the Institute of Aeronautical Sciences should act as adviser in the matter in conjunction with the Royal Aeronautical Society. The trophy, which was known as the Musick Memorial Award, was founded in 1938 as a Memorial to Captain Edward Musick and his six companions who were lost in January, 1938, in the South Pacific on the first commercial flight between the United States and New Zealand, and the first award of the trophy had been made to Mr. A. Gouge, chief designer to Messrs. Short Brothers (applause). The Musick Memorial award, continued Major Lester Gardner, was to be presented annually to the group, body or individual who had made contributions to development or improvement which, by their practical application, had become most effective in regard to the safety of aircraft, with special regard to trans-oceanic aviation, and it was a great pleasure to him to present this first award to Mr. Gouge (loud applause).

THE PRESIDENT: He now called upon Dr. George W. Lewis to deliver the 27th Wilbur Wright Memorial Lecture. The lecture was founded in 1912 in memory of that great pioneer, Wilbur Wright. It had now become the most important annual lecture on aviation in the world and had been delivered by leading authorities from America, Germany and Great Britain. It had been customary for the Council to arrange for this annual lecture to be given alternately by an Englishman and a non-British subject, and this year they were indeed fortunate in having as the lecturer Dr. George Lewis of America.

Continuing, the President said it had been customary to send a telegram on the occasion of these lectures to Mr. Orville Wright, the brother of Wilbur

Wright, who was so closely associated with him in his first pioneer flights. Therefore, the Council had sent the following telegram to Mr. Orville Wright:—

> "On May 25th your distinguished countryman Dr. George Lewis will deliver the 27th Wilbur Wright Memorial Lecture before the Royal Aeronautical Society. The Council and all members of the Society send you their most cordial greetings on this occasion and wish to assure you how, every year, their appreciation grows of the great pioneering work carried out by your brother and yourself which is steadily leading to a complete revolution of the civil means of transport in the world.
>
> FEDDEN, *President.*"

To that telegram the following reply had been received from Mr. Orville Wright:—

> "Your telegram of greetings received and much appreciated. Please extend to Council and Members my thanks and to Dr. Lewis an expression of my interest in his address. His subject is appropriate for a Wilbur Wright Lecture. Flight was accomplished in 1903 as a result of new knowledge in Aerodynamics acquired through wind tunnel Research. Progress in aviation since that time has greatly extended the field in which research is needed, so that in importance I think research today still holds first place.
>
> ORVILLE WRIGHT."

The President added that Dr. Lewis, in the midst of his arduous duties which were very heavy at the present time, had come over specially from America to deliver this lecture. As many of those present were aware, Dr. Lewis had been for many years Chairman of the National Advisory Committee for Aeronautics and President of the Institute of Aeronautical Sciences, and his able direction of the Langley Field Memorial Laboratories is known throughout the world. It was right to say that one of Dr. Lewis' greatest achievements has been his steadfast and continual effort in the interests of research. He had gathered around him a splendid body of research workers, had fostered a real spirit of loyalty and had built up a unique team (applause).

SOME MODERN METHODS OF RESEARCH IN THE PROBLEMS OF FLIGHT.

By GEORGE W. LEWIS, F.I.Ae.S.,

Director of Aeronautical Research,
National Advisory Committee for Aeronautics.

INTRODUCTION.

As a guest of the Royal Aeronautical Society, I wish first to express my sincere appreciation of the opportunity to join those others who have appeared before you in years past to present the Wilbur Wright Memorial Lectures. To those of us who are primarily concerned with the scientific aspects of aviation this continuing series of lectures, now nearly as old as the art of human flight itself, is the finest tribute that could be offered in honour of the accomplishments of the Wright brothers. It is on this account that I feel most sincerely the honour and privilege that has been granted me through your invitation to present the Twenty-seventh Wilbur Wright Memorial Lecture.

The title—"Some Modern Methods of Research in the Problems of Flight"—is, I confess, somewhat ambiguous. At the time it was selected, some months ago, several investigations then in progress gave promise of results sufficiently

interesting to be included. As is frequently the case in research, investigations that at one time appear to be drawing to a conclusion later open up fields for even more extensive research, and the ultimate goal appears as remote as ever. In consequence, I am now hesitant to dignify the equipment and methods to be described with the broad adjective " modern " in any conclusive sense. What is modern to-day will be obsolescent to-morrow; yet it is perhaps instructive as a guide for the future to consider those things which were modern or novel in the past.

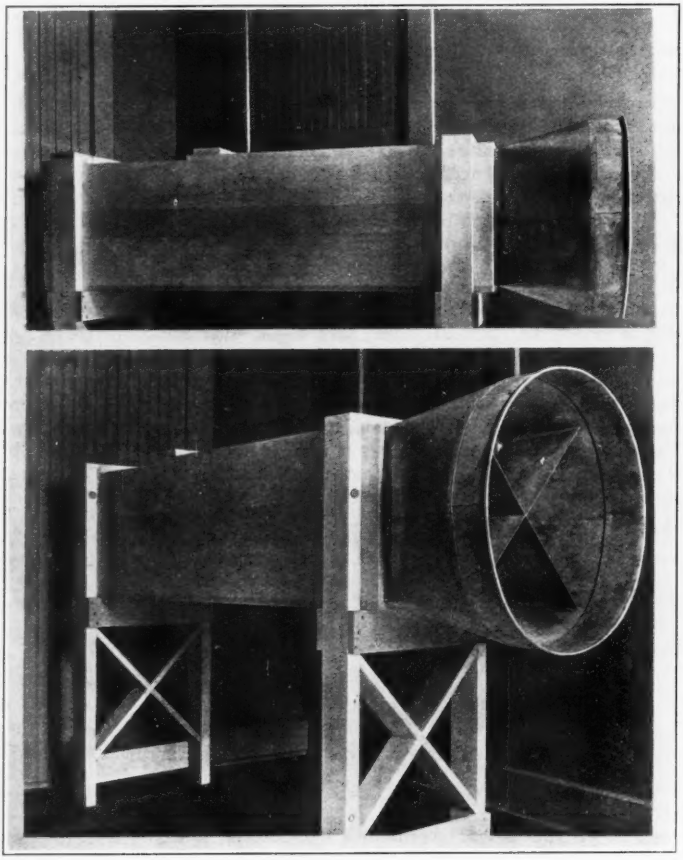


FIG. 1.
Replica of the Wright brothers' wind tunnel.

Through personal relationships with Orville Wright and through investigations of the early history of aviation it has been my privilege to attempt some estimate of the outstanding qualities and contributions of the Wright brothers (reference 1). In their day the accomplishment not only of flying the first successful power-driven aircraft, but of constructing the research equipment to provide design data and of constructing both aeroplane and engine themselves was indeed

remarkable. The methods and results deserve the term " modern " in the highest sense, in that they were far in advance of the contemporary art, and served as the basis for unprecedented practical applications.

Through the courtesy of Orville Wright some information on the Wright brothers' wind tunnel and the investigations conducted is available to me, and this subject will constitute the first section of the lecture.

RESEARCH IN THE WRIGHT BROTHERS' WIND TUNNEL.

Fig. 1 shows two views of a replica of the original Wright brothers' wind

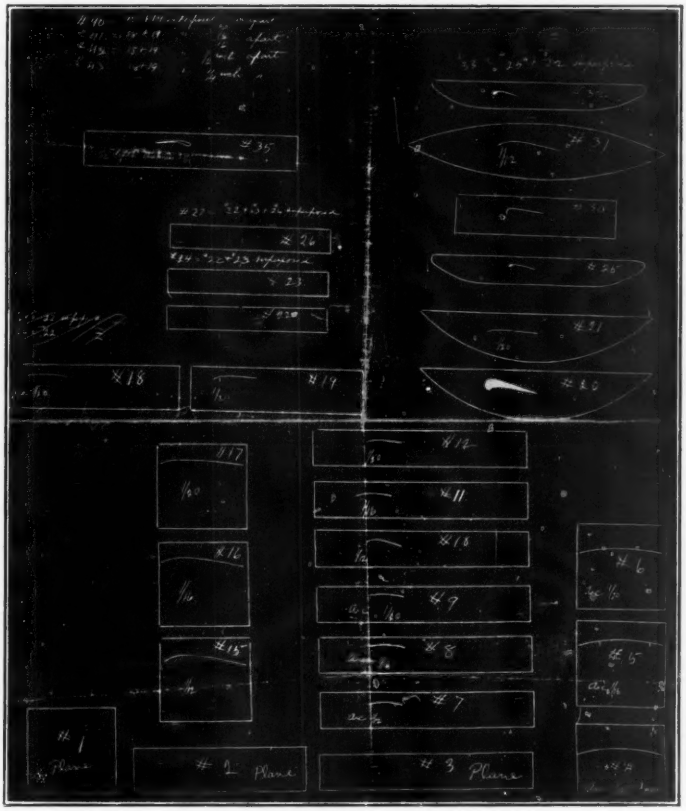


FIG. 2.

Reproduction from the original research programme (1901).

tunnel. The propeller was mounted to run in the circular ring just upstream of the straightening vanes. The tunnel itself was 5 feet long, and the test section was square in elevation, being 22 inches on a side. The speed attained was about 27 miles per hour, or 40 feet per second.

Fig. 2 is a reproduction of, I quote Orville Wright, " The original plottings (made December, 1901) giving the profile and plan form of some of the airfoils measured in the wind tunnel in 1901." In this figure I wish to invite your

attention particularly to models 7, 8, 9, and models 10, 11 and 12. Here is shown the test programme for the first investigation conducted in the United States on a systematic series of aerofoils. Models 7, 8 and 9, it will be noted, are circular arc plates with systematically varied camber; models 10, 11 and 12 have the same amount of camber in a more forward location. These models had approximately 1 inch chord and 6-inch span, giving an aspect ratio of 6, now standard for aerofoil tests in most aerodynamic laboratories. Systematic investigations on the effects of plan form, aspect ratio, biplane gap-chord ratio, and some miscellaneous studies were also conducted.

This is indeed a surprising research programme for the year 1901. I wish to emphasise particularly the broad fundamental point of view it shows. So clear was the Wright brothers' appreciation of the basic factors in the problem that they included all but one of the important variables that have since concerned us in wing and aerofoil research. In this respect most subsequent research along this line appears mainly to have been in extension and refinement of this basic outline. Since it was never published, the research programme clearly bears the independent approval of eminent research scientists in this field, who have almost universally employed the same method of attack.

We turn next to the balances employed for measuring the forces. Fig. 3 shows a diagram and reproduction of a photograph of the original lift measuring balance. The legend, as follows, is Orville Wright's own description:—

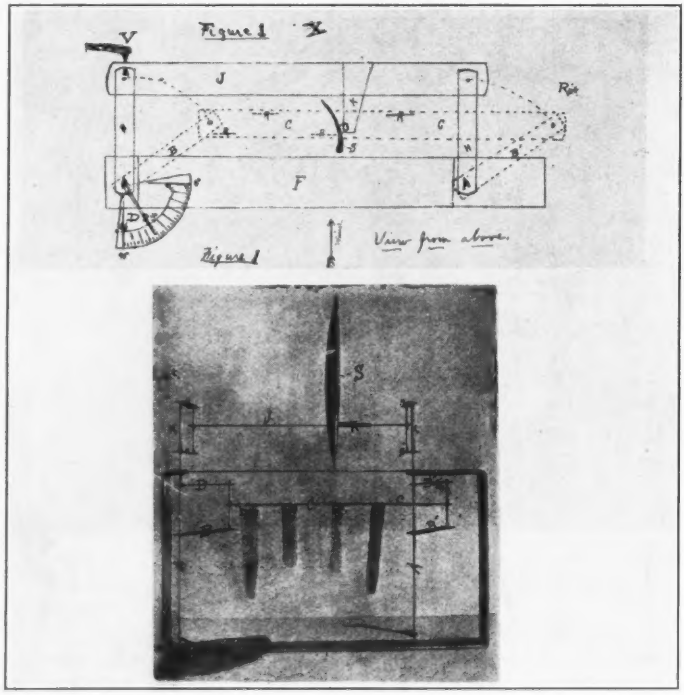


FIG. 3.

Reproductions from original sketch and photograph of the lift measuring balance (1901).

LIFT MEASURING BALANCE.

Letters correspond with parts shown in photograph and diagrammatic sketch, Fig. 1.

F	Frame. Mounted on floor of tunnel at 90 degrees to air stream.
D	Dial graduated in degrees.
P	Pointer mounted on axle A.
A, A	Vertical axles.
B, B, B, B	Horizontal arms mounted on axles A, A.
C	Cross bar swinging on arms B, B, B, B.
R, R, R, R	Resistance surfaces used instead of a square plane to avoid deflecting direction of air current striking surface S. They had no definite area themselves but together with the cross piece C had a pressure equal to that of a square plane of 8 square inch area, mounted at 90 degrees in the place of the surface S.
H, H, H, H	Horizontal arms mounted on friction sleeves T, T.
T, T	Friction sleeves fitting over axle A, A.
J	Cross bar supporting the surface S.
S	Surface to be measured mounted on K at various angles to be measured.
K	Mounting piece attached to K.

The pressure on the surface S tends to move the pointer P toward 90 degrees, while the pressure on R, R, R, R, tends to move the pointer back towards zero. Before taking a reading the arms H, H, must be adjusted always through the friction sleeve T, T, parallel to the air stream. Then the sine of the angle indicated by P multiplied by eight and divided by the area of the surface being measured will equal the lift of the surface S in per cent. of pressure on normal plane of equal area.

The method of measuring drift, or drag, was equally ingenious. An auxiliary balance, shown in Fig. 4, was used. This balance measured the ratio of drift to lift directly as the tangent of an observed angle—a method which may appear tempting even now to the wind tunnel investigator, overburdened as he is with the calculation of induced interference effects. The photograph shows a replica of the original balance and the legend, as previously, is Orville Wright's description :—

DRIFT (DRAG) MEASURING MACHINE

Fig. 4 represents diagrammatically the D/L measuring machine.

H, H	Parallel arms mounted on axles AA.
C	Connecting links between arms HH.
S	Aerofoil to be measured, mounted on connecting links C.
E	Dial graduated in degrees.
P	Pointer attached to arm H.
R	Represents resultant of all pressures on aerofoil S.
L	Represents Lift.
D	Represents Drag.
	Then tan angle HAH', as indicated by pointer P, gives D/L.
F	Frame (see photograph).

In practice we usually rotated the frame about the point X to change the angle of attack, in which case the angle indicated by the pointer P was added (subtracted when the angle was negative) to the angle of attack. We had a large scale of degrees, not shown in the photograph, on the floor of the tunnel on which the instrument was mounted.

It will be observed that the surface S, being mounted on a parallelogram, will maintain the same angle of attack at all positions of the arms HH; that the

drag of the aerofoil, being balanced directly against the lift of the same aerofoil, knowledge of the exact wind velocity is not required; that so long as the axles A, A are kept in a vertical position the weight of the surface S needs no counterbalancing; that the position of the centre of pressure on the aerofoil S does not affect the readings, since the pressures always act on a radius equal to the length of the arms H.

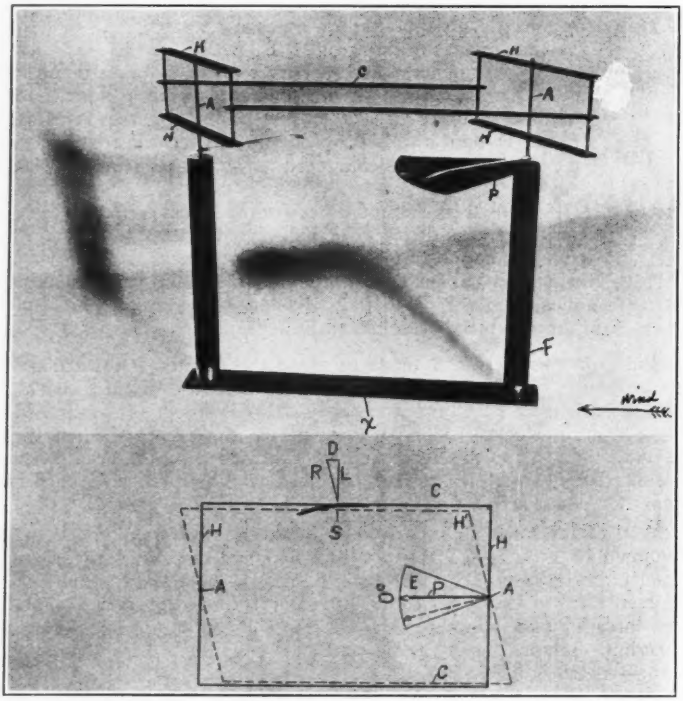


FIG. 4.
Sketch and replica of the D/L measuring balance.

The force measuring arrangements may at first appear complicated, but to those acquainted with the modern techniques of wind tunnel research a number of outstanding features will immediately become apparent. The question of translating the recorded measurements into forces effective on a full-scale machine is the crux of the whole situation, and in this respect the Wright brothers revealed not only considerable understanding of mechanics, but an astonishing appreciation of the pitfalls involved in small scale wind tunnel testing.

Orville Wright has given me a verbal description of the whole process, which unfortunately I must reproduce in my own words. The lift, as noted before, was balanced directly against a set of resistance plates which had previously been calibrated against the drag of a square flat plate of known area in the same position in the air stream as the wings to be investigated. The drift was measured in per cent. of the lift. Thus far the steps taken were mainly to obviate difficulties resulting from non-uniform and non-constant velocity in the air stream, although care had previously been taken to reduce these to a minimum. Still, however, no direct measurement of actual forces to be expected on the full-size

wings was available. This was accomplished by the use of a glider tested in 1902. This glider had a wing scaled up from one of the models tested in the wind tunnel and by means of glide tests in winds of known velocity it was possible to determine the lift and drag as actual forces. These tests in effect calibrated one of the wings tested in the wind tunnel for full-scale conditions, and since the relation of the other wings to this wing was known from the wind tunnel measurements, the characteristics to be expected from all the wings when flown full size were directly indicated by the wind tunnel data.

This description from Orville Wright reveals, I believe, one aspect of the Wright brothers' research work that has never been realised before—the fact that they adopted an expedient in the year 1901 that automatically corrected measurements at small Reynolds number to the Reynolds number encountered in flight. By the steps described they reduced the critical assumptions to one: That the order of merit of the aerofoils would not be seriously affected by Reynolds number, though the absolute values of the coefficients might change.

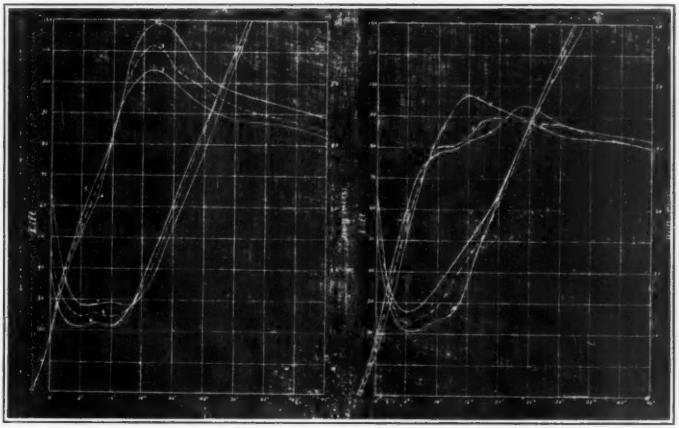


FIG. 5.
Reproduction from original plots of data (1901).

It was not until about thirty years later that aerodynamic research settled this question and showed that at least for a number of critical aerodynamic characteristics the assumption was valid.

One other point of interest in this connection deserves note. Using the average flight measurements on their 1902 glider and the wind tunnel results on models; the Wright brothers calculated that the unit drag of a square flat plate of large area was equal to the square of the speed in miles per hour multiplied by the coefficient 0.0033. At the time, Orville Wright has told me, they had their choice among figures varying from 0.0025 to 0.0055, based on the tables of other investigators. Much subsequent research has led to general adoption of the figure 0.00328 for the coefficient in question; truly astonishing agreement with the value reached by the Wright brothers through averaging a series of results obtained in flight measurements on a glider in the year 1902.

The results of the investigations on the aspect ratio (6) wings of various cambers are shown in Fig. 5. These were reproduced directly from the original plots made in December of 1901. The first item of interest is the scales employed, which show the lift in per cent. of the resistance of a square flat plate and the drift of the wing in per cent. of its lift. The shape of the curves is sufficiently familiar to all concerned with aerodynamics that they need no further identifica-

tion. Models 7, 8 and 9, it will be noted, show the effects of camber with which we have later become familiar in more detail. In present non-dimensional terms the drag coefficient of a square flat plate is approximately $1\frac{1}{4}$, so the figure shows that the maximum lift coefficients obtained with the circular arc aerofoils varied from about 1.3 to about 1.5, values clearly in agreement with our modern knowledge of aerofoils. With this information it is amply evident that the Wright brothers, through their investigations in 1901, gained a clear physical conception of the behaviour of wings on which to base the design of their successful "flying machine." Their subsequent rapid progress to the goal of sustained flight and the technical and scientific achievements that have followed in later years I need not recount.

Trends of Wind Tunnel Development.

Following the establishment of large Government laboratories for the study of aerodynamic problems scarcely a year has elapsed in which new contributions to wind tunnel design have failed to appear. The general trend of improvement has been in increased size of the wind tunnel to permit the use of larger models, increased speed of the air stream to keep up with the increase in performance of the aeroplane, and provision for investigations at larger Reynolds number by the use of high density air. The improved design of wind tunnels has been dictated largely by the necessity to solve the problems that arise in aeroplane design. With designers' vision frequently reaching far in advance of contemporaneous development, it has been necessary to improve the wind tunnels year by year so that data obtained from model tests could be applied directly in the design of new types of larger and faster aeroplanes.

Since the days of its early growth, the National Advisory Committee for Aeronautics has endeavoured to emphasise this aspect of aeronautical research, and has therefore followed the policy not only of undertaking theoretical analyses of aeronautical problems, but in so far as possible of anticipating the future needs of aeroplane design by the construction of wind tunnels having special characteristics. As a few examples of this policy the following equipment at Langley Field may be mentioned: The variable density wind tunnel for aerofoil research at high Reynolds number, the 20-foot propeller research tunnel, the full-scale tunnel, and the high speed jet tunnels for aerofoil research under propeller operating conditions. Since these tunnels and the results of their work are well known in aerodynamic circles, I shall pass over them with little further comment.

More recently, anticipation of further increases in aeroplane performance led to the construction of the Committee's 8-foot 500-mile per hour wind tunnel. The results of investigations in this tunnel have proved effective in providing design information for the development of high-speed aeroplanes. It may be said that the design of new wind tunnels of such types as this is predicated almost entirely on present and future problems that are apparent when a survey is made of the performance characteristics that represent reasonable engineering possibilities for future military and commercial aircraft.

Realisation of the anticipated advances in aircraft development as to size, as well as speed, has made it necessary to augment fundamental or basic research with applied research on special models. Such models having spans up to 40 feet are now investigated in the full-scale wind tunnel. The models themselves are complete with control systems and power plants. The careful investigation of highly refined models is well repaid when they represent large aeroplanes such as have recently been built or contemplated.

The Committee's most recent efforts in continuation of this policy are exemplified in the new 19-foot pressure tunnel, which is shown in Fig. 6. This tunnel, designed in 1937, is now being placed in operation. Having a throat diameter of 19 feet, it can accommodate large-scale models to be tested at pressures from sub-atmospheric up to several atmospheres, and at air speeds in excess

of 250 miles per hour. It is planned to use this tunnel in extending the types of investigation that have been carried on in the propeller research tunnel and in the full-scale tunnel.

A marked trend during the past few years has been toward the use of dynamic models for investigation of the stability and control characteristics of aeroplanes. The initiation of this useful method we owe to the Aeronautical Research Committee in their laboratories at Farnborough, where the original free-spinning wind tunnel was developed. Others have followed, and at present every major aeronautical research laboratory has included a free-spinning wind tunnel as part of its equipment.

Another trend in certain classes of wind tunnels has been a departure from the direct measurement of forces and moments on an aeroplane model toward the more fundamental research that can now be applied by valid theoretical methods to the prediction of aerodynamic characteristics. This trend, associated here with the work of Professor B. M. Jones, as well as with that of Dryden and Jacobs in the United States, has been directed toward the use of carefully controlled experimental conditions, approximating as closely as possible the conditions encountered by aeroplanes in flight.

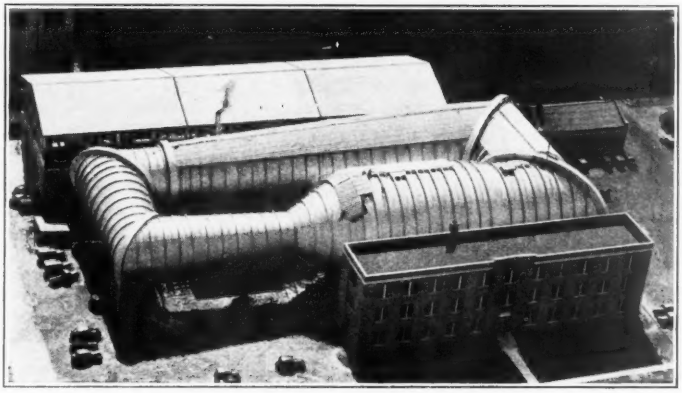


FIG. 6.

The N.A.C.A. 19-foot pressure tunnel.

To summarise these introductory statements then, we observe a tendency for wind tunnels to become more specialised, resulting in fruitful researches for each type in its own special field of aerodynamics. In the main body of the lecture I shall try to illustrate this thesis by considering three special types of wind tunnel, each having application to a special field of aerodynamics directly related to the fundamental problems of aeroplane design.

LOW TURBULENCE WIND TUNNEL.

The first, and probably most important, aerodynamic problem faced by the aeroplane designer is that of the speed, range, and efficiency of the aeroplane. These factors all may be considered under the broad field of aerodynamic efficiency and the main object in this field may be stated very simply; it is the reduction of drag.

Mainly investigations in aerodynamic laboratories have centred around the characteristics of the wing, even as did those of the Wright brothers, because it is simple and represents many of the fundamental problems of aerodynamics. The classical theory of wings of finite span further simplified the problem so that

the principal effort could be devoted to investigation of the characteristics of aerofoil sections.

In general, since the construction of the variable density wind tunnel, at the suggestion of Dr. Max M. Munk, the aerofoil research at Langley Field has been conducted in this wind tunnel, though correlation in other wind tunnels and in flight has been undertaken as deemed advisable. During recent years this work has been conducted under the supervision of Eastman N. Jacobs, whose contributions in development of improved aerofoils have received gratifying recognition throughout the world. Among Jacobs' co-workers, those most actively engaged in this work have been Messrs. Abbot, Stack, von Doenhoff, Pinkerton, and Sherman.

Turbulence and velocity fluctuation in the air stream of wind tunnels have long been a matter of concern in the broad field of fluid mechanics as well as in aerofoil research proper. For the interpretation of wind tunnel results to conditions existing in the free atmosphere, a helpful simplification resulted from the concept that turbulence in the atmosphere is of such a nature that its effect on the transition from laminar to turbulent flow in the boundary layer of an aeroplane wing may often vanish under free flight conditions. Data tending to confirm the validity of this concept were obtained independently in Germany and in the United States about four years ago (references 2 and 3). Although it may not be strictly the case under all conditions, the effective non-turbulence of free air provides a useful criterion and reference standard of wind tunnel design; that the condition of vanishing effect of wind tunnel turbulence on the transition from laminar to turbulent flow in the boundary layer be sought.

The point might be of academic interest only were it not that a number of recent investigations from various sources (references 4, 5, 6 and 7) have given some indication of the possibility of more extensive laminar boundary layers and consequent lower drags than have previously been available with the aerofoil sections commonly employed in aeroplane design. Tests in the N.A.C.A. smoke tunnel, as well as G. I. Taylor's theoretical investigations suggested the possibility that in the low turbulence conditions encountered in flight transition on an aerofoil might tend to remain at a constant position with increasing Reynolds number rather than to move forward as indicated in turbulent wind tunnels (reference 8). The consequences as to aeroplane performance appeared so important that the possibilities could not be overlooked and active design of a low turbulence wind tunnel was initiated in the spring of 1937.

This tunnel, designed in accordance with Jacobs' suggestions for achieving low air stream turbulence, was completed in the spring of 1938. Since that date our laboratory staff has been actively engaged in investigating the entire problem of transition in relation to aerofoils under the low turbulence conditions attained. In accordance with the usual policy, the aspects of the problem that appeared to have direct relation to practical application were emphasised. The attempt was made, however, to simplify the investigation sufficiently so that it became essentially fundamental in character without losing sight of the practical objective. The foregoing considerations led to the design selected for the present low turbulence wind tunnel, which is in many respects the most highly specialised aerofoil research equipment yet constructed by the National Advisory Committee for Aeronautics.

The test section (Fig. 7) is 3 by $7\frac{1}{2}$ feet and is arranged for the testing of large models of several feet chord and only 3-foot span in essentially two-dimensional flow.

The most difficult problem was to reduce the turbulence to the desired level. The usual methods of measurement were not sufficiently sensitive. Direct comparisons of the transition effects on aerofoils, as observed in flight, in the new tunnel, and in other tunnels, were therefore made. These comparisons indicated that the turbulence of the new tunnel in so far as its effect on transition is

concerned was well below the level of other N.A.C.A. wind tunnels, and in most cases below the level inferred from flight tests.

For example, values of the critical Reynolds number for transition have been found that exceed 6,500,000 when interpreted in terms of the equivalent flat plate Reynolds number used by B. M. Jones (reference 4). The maximum values of the equivalent flat plate Reynolds number reported previously were those given by Jones as approaching 5,000,000. Comparisons made to date suggest that the transition was hastened in flight by other disturbing effects. In the tunnel,

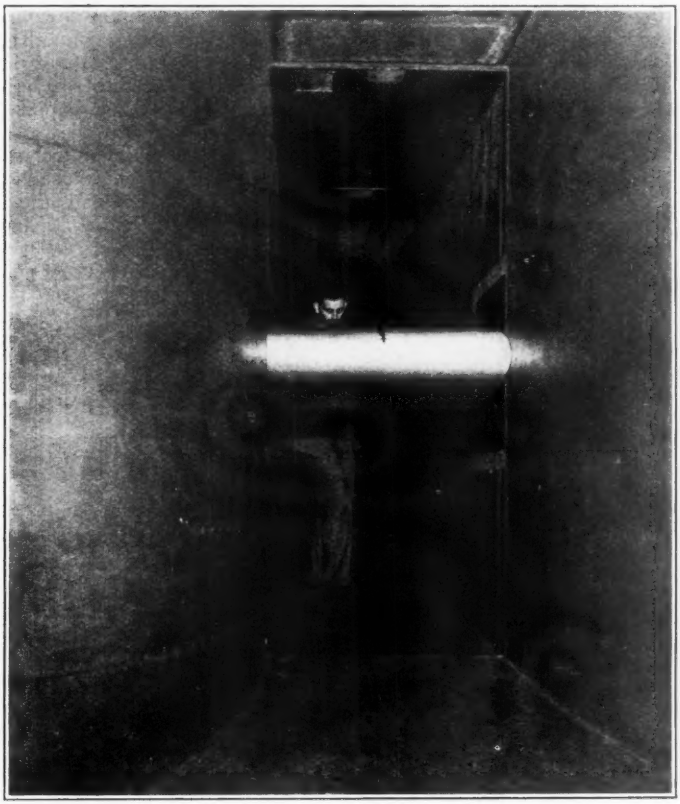


FIG. 7.

Test section of N.A.C.A. low-turbulence tunnel.

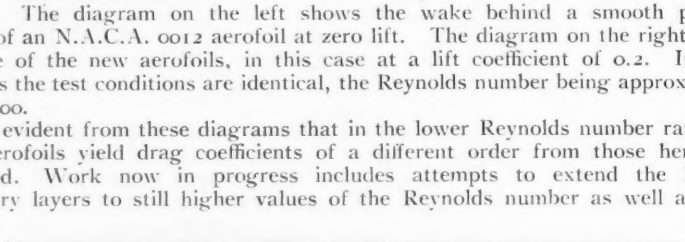
disturbances such as surface roughness and vibration were carefully avoided. Nevertheless, it still does not appear probable that the turbulence has been reduced to the effective zero level, but the level does appear sufficiently low to justify certain conclusions based on the investigations in this tunnel pending further research in flight.

In many ways the preliminary results of these investigations have proved illuminating. Under conditions of vanishing turbulence, it appears that transition may be of a different character than in the usual tunnel. The laminar boundary layers ahead of transition often follow accurately the laminar boundary layer theory and appear to be free or nearly free from unsteadiness or fluctuations

of the type observed by Dryden. Thus the skin friction drag produced by these laminar layers at the comparatively large Reynolds numbers attainable is no greater than that predicted by the laminar boundary layer theory. Aerofoils theoretically designed to take advantage of true low drag laminar boundary layers over a major portion of their surfaces showed spectacular results from the standpoint of drag reduction when tested under suitable conditions in the two-dimensional flow tunnel.

These statements may best be illustrated by the photographs in Fig. 8, showing a bank of manometer tubes so connected to a wake survey apparatus as to measure the total head defect behind an aerofoil mounted in the low turbulence tunnel. The diagram on the left shows the wake behind a smooth polished model of an N.A.C.A. 0012 aerofoil at zero lift. The diagram on the right is that for one of the new aerofoils, in this case at a lift coefficient of 0.2. In other respects the test conditions are identical, the Reynolds number being approximately 5,000,000.

It is evident from these diagrams that in the lower Reynolds number range the new aerofoils yield drag coefficients of a different order from those heretofore obtained. Work now in progress includes attempts to extend the laminar boundary layers to still higher values of the Reynolds number as well as other



N.A.C.A. 0012 aerofoil, zero lift. *Laminar-flow aerofoil, $C_L = 0.2$.*

FIG. 8.

Comparison of wake behind aerofoils. Aerofoil chord, 5 feet. Reynolds number, 5,350,000.

phases of the subject. Unfortunately I am not in a position to report further details of these investigations at the present time, but have tried here to indicate the nature of our efforts to further present knowledge of the transition from laminar to turbulent flow in the boundary layer. Our studies are now directed toward the actual mechanism of transition under the simplified conditions which appear susceptible of almost complete experimental control.

THE GUST TUNNEL.

The structural integrity of aircraft as affected by aerodynamic loads has been the major concern of a group on the Committee's staff under the supervision of Richard V. Rhode for a number of years. Messrs. Lundquist and Donely, as well as other members of the Committee's staff, have contributed to the results thus far obtained. You may recall the justly deserved recognition of Rhode's work when its publication became possible.

To state, then, the problem of aerodynamic loads, it has been evident for many years that atmospheric gusts give rise to loads of considerable magnitude on aeroplane structures. With the continuing increases in the size and speed of

transport and bombing types, it has become increasingly apparent that these gust loads constitute the most important conditions for which the structure should be designed because (1) the relative structural weight tends to increase with increasing size, making it necessary to reduce the design loads of large aeroplanes to a minimum; (2) increased size is, in general, accompanied by sufficiently increased wing loading to result in greater gust loads because of the reduced alleviation caused by the motion of the aeroplane with the gust; (3) the gust loads increase directly with the speed of flight.

In anticipation of the coming importance of the problem of gust loads the available data on the structure and intensity of atmospheric gusts and on the accelerations experienced by aeroplanes flying through them was reviewed in 1930 (reference 9). As a result of this survey it seemed desirable to obtain extensive acceleration data under actual operating conditions in order that a sound basis for the establishment of gust load criteria might be provided. It was further apparent that air speed measurements should be made simultaneously with the acceleration measurements in order that the results might be reduced to a reasonably rational common denominator, viz., an " effective " gust velocity. Since the co-operation of airline operators was desired, it was necessary to devise an instrumentation so simple and reliable that there could be no reasonable objection to installations on transport aircraft. For this and other practical reasons, an instrument, now known as the N.A.C.A. V-G recorder, was designed. This instrument (reference 10) combines an accelerometer element and an air speed element in such a way that the stylus plots simultaneous values of the two quantities on a smoked glass plate during any desired period of operation. As there is no time scale, the instrument does not require electrical connections or clockwork and it therefore requires no attention in service other than routine examination at reasonably long intervals.

This type of instrument has made possible, with very few units, the collection of the desired extensive data. There have been accumulated on commercial transport aeroplanes up to March 20, 1939, 67,300 aeroplane hours of flying time, representing approximately 10 million miles under widely varied conditions of topography, weather, etc. Fig. 9 illustrates the results thus far obtained in this phase of the investigation. With the records, it has been possible to ascertain that the probable maximum effective gust velocity (based on the sharp-edge gust hypothesis) is about 30 feet per second for an aeroplane having the characteristics of the Boeing 247, and this value is currently used as a basis for determination of gust load factors in the United States. There have been two or three exceptional cases, of course, in which the effective gust velocities considerably exceed this value, but consideration of the circumstances indicates that these cases could and should have been avoided and that they should not therefore be taken as design criteria.

Another useful service rendered by the V-G recorder has been to provide after the event a record of some of the circumstances attendant to accidents. One such case may merit description. In the course of military manœuvres a large aeroplane inadvertently fell out of control and in the resulting dive the pilot was forced to make a rather abrupt recovery. Although no damage to the aeroplane was noted at the time, on its return to its base both wings were found to be buckled to the point of yielding of the material. The presence of a V-G recorder in this aeroplane showed that the acceleration sustained exceeded by approximately 0.1 g. the design load factor for yielding of the wing material. In this case the V-G recorder provided a structural test in flight, gratifying as it was unexpected, of the validity of stress analysis methods employed in the design of large aircraft.

The structural problems raised by the existence of atmospheric turbulence and thermal currents, through which all aeroplanes must fly, have required the development of research methods and apparatus suited to the attainment of practical solutions. Although there exists a partially developed theoretical back-

ground (references 11 and 12), which has greatly assisted our understanding of some of these problems, many of the questions are essentially quantitative in character, and to answer them requires a more or less direct experimental approach. The whole subject may be summed up in three questions:—

(*a*) What is the nature or structure of atmospheric gusts?
(*b*) How do aeroplanes react to gusts of known structure?
(*c*) How are the gusts related to the various meteorological elements?

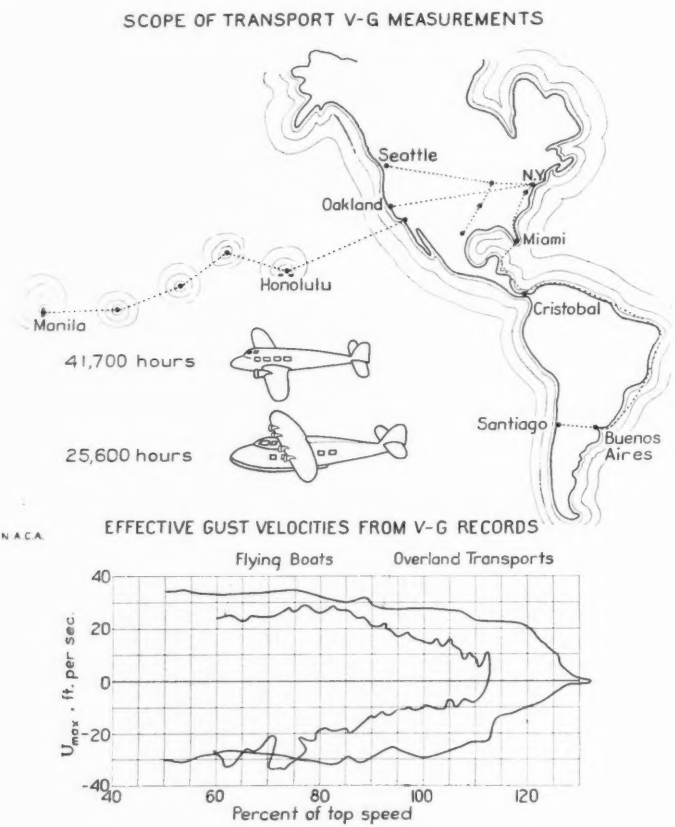


FIG. 9.
N.A.C.A. V-G research.

To assist in answering these questions an apparatus, known as the "gust tunnel" has been developed, in which it is possible to determine experimentally the reaction of suitably scaled dynamic models in controlled artificial gusts (reference 13). As an example of the part this apparatus plays in gust research, consider the first and third questions, "What is the structure of atmospheric gusts?" and "How are the gusts related to the meteorological elements?"

To find the answers a small aeroplane may be used as an instrument with which to measure the structure of atmospheric gusts at different altitudes under a variety of weather and topographical conditions. The aeroplane should be calibrated for this purpose—that is, its reaction under different given gust condi-

tions should be determined so that the results of the flight measurements can be properly interpreted.

Pending a complete answer to the second question, viz., the reaction of an aeroplane to given gusts—such a calibration is conveniently made by testing a scaled dynamic model of the aeroplane in the gust tunnel under controlled conditions. In this way, such effects as arise from the pitching motion of the aeroplane, the biplane arrangement (used in one case), and other influences can directly be taken into account.

Another direct application of gust tunnel data to aeroplane design is the determination of load factors to be used in the design of new and unconventional types. Lacking theoretical methods for reliable calculations to predict the quantitative effect of several important factors in the design, a model of the proposed aeroplane can be investigated with appropriate values of wing loading, speed, and balance under a variety of conditions in the gust tunnel. For the purpose of selecting the best conditions a model of an existing type of aeroplane on which

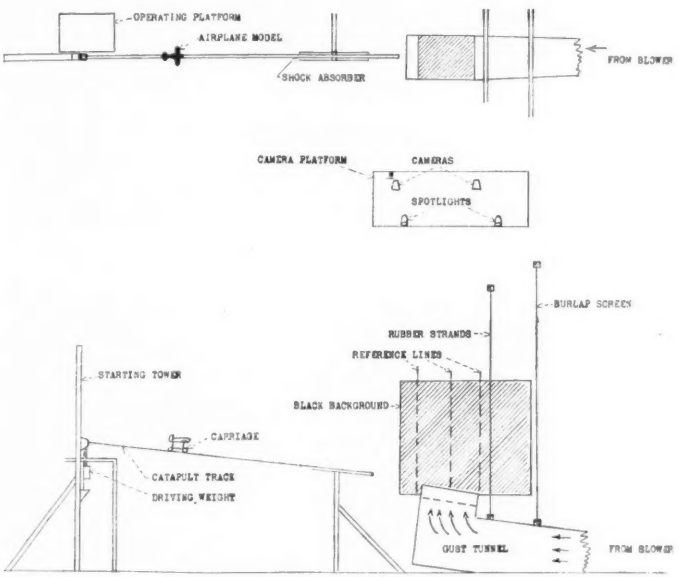


FIG. 10.

Diagram of the N.A.C.A. gust tunnel.

V-G records have already been accumulated in flight is first tested in the gust tunnel. The results of these preliminary tests serve to identify a reasonable range of gust conditions that would lead to the accelerations observed in flight on the existing type. The data obtained for the new design in the identified gusts then indicate the loads it may be expected to encounter under practical flying conditions.

Although the most conservative values are selected for the design load factors, reductions may sometimes be effected from the values that would otherwise have to be selected from the best known methods of calculations. In one case, for example, it was found safe to select gust load increments 17 per cent. less in the light condition and 22 per cent. less in the heavy condition than the values that would have been chosen without benefit of the gust tunnel.

The gust tunnel itself consists simply of an expanding rectangular channel which discharges a current of air in an upward direction. The general layout of the tunnel and associated apparatus is shown in Fig. 10. The air stream is supplied by a large Sirocco blower. The velocity of the jet is controlled through the blower speed, and the velocity distribution is controlled by suitable screening in the mouth of the tunnel. Jets of almost any desired velocity distribution may be created, although attention has thus far been directed only to linear velocity distributions ranging from the uniform distribution with a narrow boundary zone (one-third of the chord of the aeroplane model) to linear gradients in which full velocity is attained in about 16 chord lengths.

Auxiliary apparatus includes a weight-driven catapult for projecting the model into a free glide at constant speed, a system of rubber strands and burlap screen for catching the model unharmed at the end of its flight, a small automatic recording accelerometer mounted in the model, and cameras for photographing the flight path.

In operation, the model is projected down a track by the catapult. When flying speed is reached, the model, which has attained its proper trim attitude, takes off. A thrust bar that has been pushing the model at its centre of gravity is automatically retracted to clear the model. At the same time, tiny lamps at the nose and tail of the model are turned on and the accelerometer starts to operate.

The model glides at constant velocity until it enters the air jet, from which point it moves in accordance with the changing forces imposed upon it. The cameras beside the tunnel photograph the paths of the lamps at the nose and tail of the model. From these photographs, the vertical motion of the centre of gravity and the pitching motion can be evaluated. A revolving shutter, placed in front of the up-path camera, interrupts the light from the nose and tail lamps so that the lamp paths on the photograph appear as dashed lines. From the scale of the photograph and the speed of the shutter, the flight speed of the model prior to its entry into the gust is determined.

The accelerometer, which is small enough to be housed within the fuselage and light enough (approximately $3\frac{1}{2}$ ounces) for the purpose, is used to provide a direct measure of the vertical acceleration, which would otherwise have to be obtained by the unsatisfactory process involving double differentiation of the flight path. This accelerometer is air-damped and has a high frequency (130 cycles per second) so that rapid changes of acceleration can be measured accurately. The accelerometer record is synchronised with the flight path record by means of a narrow beam of light which is caused to impress a vertical line on the accelerometer film. Since the position of the light beam is known, the position of the model on the flight path is known at an instant of time marked on the accelerometer record.

After traversing the gust, the model must be arrested or caught without damage. This is accomplished by decelerating the model with a system of closely spaced vertical rubber strands until the momentum is largely, but not entirely, dissipated. At this point the nose of the model, to which is secured a small barbed spear, engages a burlap screen. The residual momentum is sufficient to cause penetration of the spear into the burlap, and the barbs prevent the model from rebounding.

The model itself may be of a special type depending on the purpose of the test, or it may be a true scaled representation of an actual aeroplane. In the latter case, the mass distribution along only the longitudinal axis is normally to scale, as up to the present time the tests have been concerned only with symmetrical conditions in the vertical plane. Unsymmetrical cases can, however, be investigated. The rigidity of the wings can be controlled within limits, and means have been devised for obtaining measurements of wing deflection on the accelerometer film.

Typical records of acceleration and flight path are shown in Fig. 11. On the accelerometer record, the double-headed arrow indicates the portion representing flight through the gust. The vertical line at the left is the synchronisation mark impressed by the light beam through which the model has flown.

Fig. 11*b* shows the record of the paths of the nose (upper) and tail (lower) lamps in the steady glide prior to entry into the gust. These lines are dashed, as previously mentioned, by a revolving shutter in front of the camera lens. Note how straight and parallel they are. Fig. 11*c* shows the lamp paths through the gust. The convergence and curvature of these lines indicate pitching and vertical displacement.

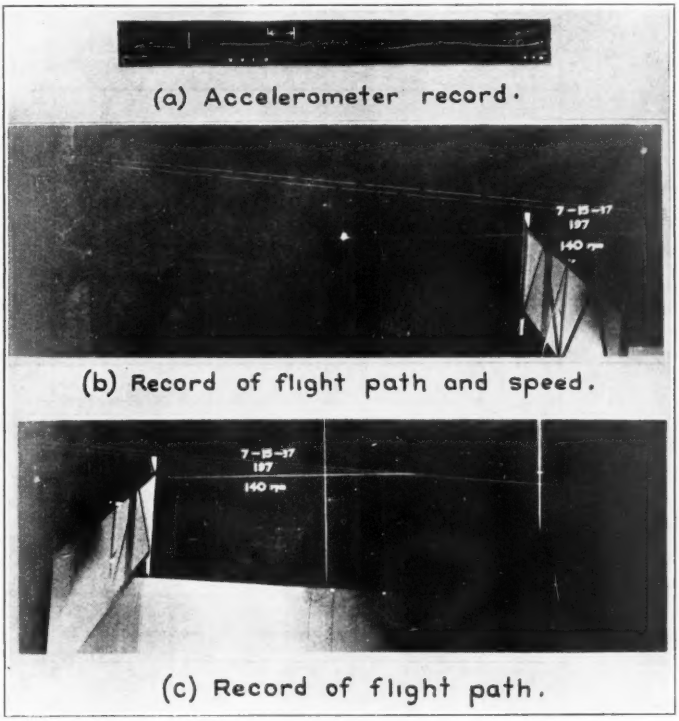


FIG. 11.

Typical records from the gust tunnel.

Typical results are given in Figs. 12 to 15. On Fig. 12 are shown histories of the several quantities measured as a conventional model traverses the gust jet. The gust profile U/U_{max} is substantially flat to a point beyond maximum acceleration and has a relatively steep gradient, the full velocity being reached in about one chord length. Acceleration, angle of attack, pitch, and vertical displacement are shown in order from the bottom. At a flight speed of 60 feet per second, the time to reach maximum angle of attack is about 0.01 second and the time to reach maximum acceleration is about 0.03 second.

Fig. 13 shown a comparison between the measured accelerations in a sharp-edge gust and those computed according to Küssner for a model with an aspect ratio of 6.7. The agreement is considered very good.

The next figure, number 14, shows that Küssner's theory is still in fairly good agreement when the aspect ratio is as low as 2.2 This is a remarkable result in view of the fact that Küssner, in applying Wagner's theory for the infinite wing to problems of finite wings, made the rather arbitrary assumption that the slope of the finite wing lift curve in unsteady flow would be reduced from that of the infinite wing in the same manner as in the case of steady flow.

Fig. 15 shows the comparison between experimental results from the XBM-1 biplane and values computed on the assumption that the slope of the cellule lift

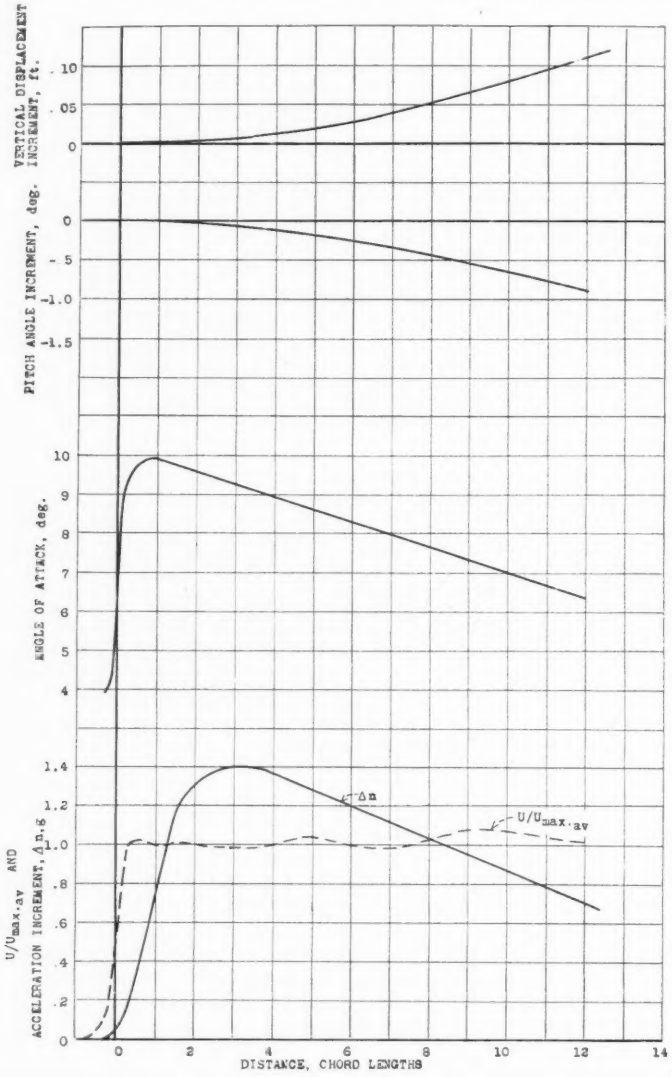


FIG. 12.

Behaviour of an aeroplane model in a sharp edge gust.

curve could be used in the calculations. Note that the abscissa here is the gradient distance rather than gust velocity as in the previous two illustrations. In this case, arbitrary substitution of the lift curve slope for steady flow fails, the experimental values being 21 per cent. greater than the computed values,

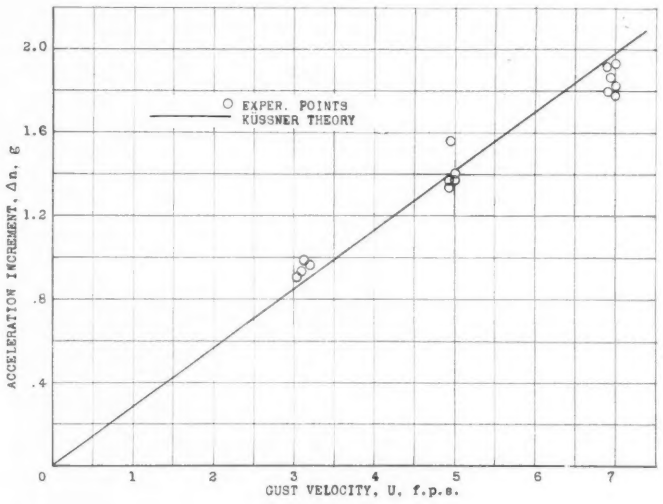


FIG. 13.

Acceleration of a monoplane with aspect ratio 6.7 in a sharp edge gust.

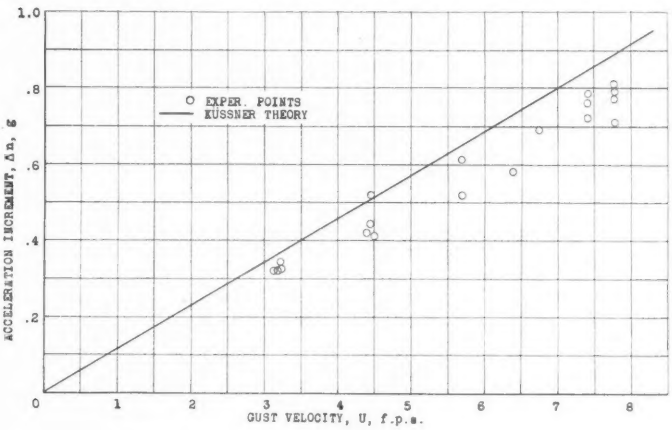


FIG. 14.

Acceleration of a monoplane with aspect ratio 2.2 in a sharp edge gust.

except at the larger gradient distances, with which the pitching of the model into the gust results in a reduced acceleration. The data from these tests are being used in the interpretation of the flight measurements of gust structure, about half of which were made with the XBM-1 aeroplane.

In conclusion of the discussion on this subject, it appears that the V-G recorder served as a basis for marked progress in the design of American aircraft toward a rational balance between the requirements of structural economy and of structural integrity. With further refinement in aeroplane design the gust tunnel appears to be a useful tool, not only for achieving a closer approximation in the balance between economy and safety, but for continuing fundamental investigations on the nature of atmospheric disturbances. It is evident from the work thus far conducted that there is still a broad field of research ahead in those subjects. Thus far I believe it may be said that the gust tunnel has fully justified the effort put forth in its development.

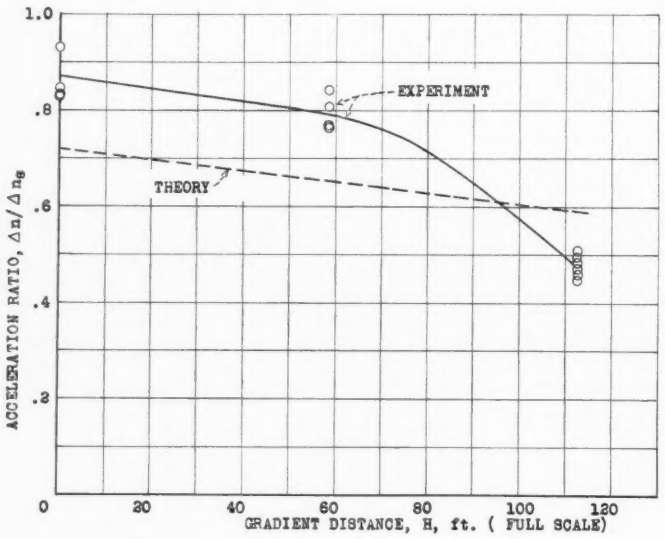


FIG. 15.

Acceleration of a biplane in gusts of various gradients.

A FREE-FLIGHT WIND TUNNEL.

Problems of stability and control have long been recognised as one of the major factors in the aerodynamic design of an aeroplane affecting safety in flight. In this field, in particular, a survey of the literature reveals very extensive activity on the part of all major aerodynamic laboratories. Yet with the development of newer, larger, and faster aeroplanes of novel design, both broad and detailed problems continue to arise, and the field remains as active as ever.

For this reason a portion of the Committee's staff is organised into a group whose major attention is devoted to problems of stability and control. The work was conducted under the supervision of Fred Weick from 1929 to 1937. Messrs. Zimmerman, Soule, Wenzinger, Shortal and Jones, assisted during various parts of this period, and Mr. Zimmerman originally suggested and developed the model free-flight wind tunnel which will be described in this section of the lecture.

In the early stages of the general stability and control investigation it rapidly became evident that the problems of stability and control were intimately associated with the development of high lift devices demanded by the design trend toward higher wing loadings. Further, it was evident that the most pressing problems then related to lateral stability and control principally at high angles of attack. On this basis extensive investigations (reference 14) were made in

the 7 by 10-foot wind tunnel covering all promising suggestions for improved high lift and lateral control devices that came to the attention of the Committee. These investigations were supplemented in the full-scale tunnel and in flight (references 15 to 18, for example) on such arrangements as were found promising in the smaller wind tunnel. This work is summarised in reference 19. Although the immediate results might be considered negative in that no outstanding individual improvements were found, the experience gained in the investigation led to a much clearer understanding than existed previously of the stability and control requirements in design. Several developments arising from the investigation are now coming to be accepted by a number of designers for certain classes of aircraft. Among these may be included the reduction of stalling hazards by the limitation of longitudinal control and by the use of novel landing techniques (reference 20), and the simplification of control co-ordination by the use of " two control operation " (references 21 and 22). It is believed that marked improvements in the safety of private owner aeroplanes, at least, may result from these steps. Furthermore, design methods (references 23 and 24) were developed for

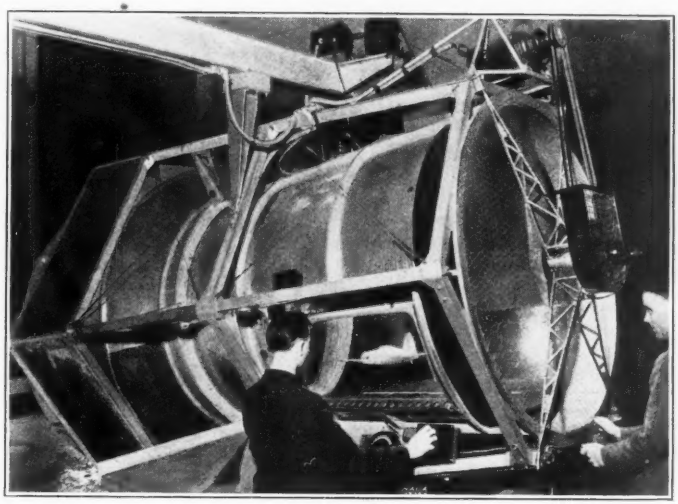


FIG. 16.

The N.A.C.A. 5-foot free-flight tunnel in operation.

the longitudinal as well as the lateral control and stability, which if carefully applied provide a straightforward method of assuring that no gross instability or lack of control in the normal flight range will be encountered in a new design of any reasonably conventional type.

Recent design trends have brought the question of the detailed stalling characteristics of three-dimensional wings more critically to our attention and it is now recognised that these constitute a design problem in themselves, distinct from the general stability and control characteristics in the normal flight range. The wing-tip slot, originally developed in England by Mr. Handley Page and his associates, is recognised as an effective expedient for improving lateral stability and control near the stall. Recognising that certain penalties would have to be paid in the way of drag or mechanical complication and possibly in icing troubles for the use of slots, the Committee has investigated the possibilities of other methods for achieving stability of a wing near the stall. Starting from the early work of Glauert and others, theoretical methods (references 25 to 28) have now

been developed by which the stalling characteristics of the wing can be adjusted to a fair degree of approximation in preliminary design. The designer has available in this connection not only the use of tip slots, but the use of washout and of varying aerofoil section along the span. Using the available information, he can now design with sufficient accuracy to assure no gross instability not only in the normal flight range, but at speeds near the stall. A simple and rational expedient adopted in one case for the design of a small aeroplane (reference 29) was the use of a rectangular wing with rounded tips, the stalling characteristics of the aeroplane being adjusted to suit by variation of the fillets in the early flight tests.

From the research point of view then, the basis for a solution of the problems of stability and control thus far discussed appears to have been reached. For the time being it would appear that more detailed refinement and specific rather than general problems will concern the research worker in this field.

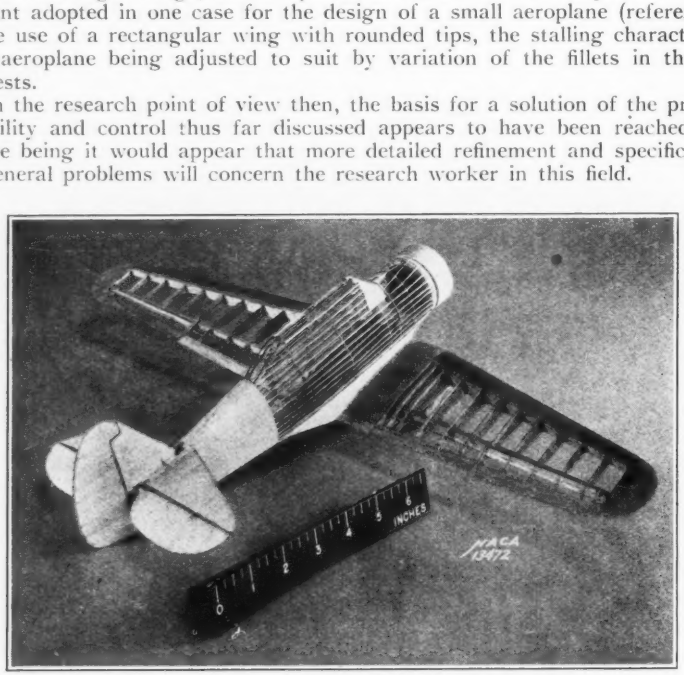


FIG. 17.

Aeroplane model for the free-flight tunnel.

It has been found, for example (reference 30), that the dynamic longitudinal stability of an aeroplane as calculated from the classical theory has little relation to the pilot's judgment of its flying and handling characteristics. This, though a negative result, suggests a field of investigation in refinement of the aeroplane's responses, on the one hand to accidental disturbances encountered in flight, and on the other hand to the characteristics and capabilities of the human being as a pilot.

Another perhaps more practical field of investigation is the individual characteristics of new aeroplane designs. Particularly in the case of large and expensive aeroplanes it appears that a new method of predetermining the flying and handling characteristics is desirable.

On this basis, and with background experience in development of a free-spinning tunnel, following the original introduction of the type at Farnborough, the Committee felt that the attempt to develop a free-flight tunnel was amply justified.

Fig. 16 shows the present 5-foot diameter tunnel (reference 31) in operation. The tunnel itself has only one unconventional feature. It is suspended on trunnions so that the inclination can be varied from horizontal to about 25 degrees

below the horizontal. Air speeds up to 25 feet per second can be attained. As shown in the photograph, two operators are required. The operator beside the tunnel has the task of maintaining the inclination and air speed in proper co-ordination with the gliding characteristics of the model under test. The operator of the model at the end of the tunnel has several functions; first, he must maintain the model laterally in the centre of the tunnel by use of the rudder, to compensate for lack of stability in azimuth; second, he operates the controls on the model in studies of unsteady flight conditions; and third, he observes the general flying and handling characteristics of the model. This last function follows almost automatically from the difficulty encountered in achieving the desired flight conditions.

The type of model used in the tunnel is shown in Fig. 17. Operation of the controls is effected by the use of small electro-magnets mounted in the nose of the model (Fig. 18). The electro-magnets are supplied with current through a fine

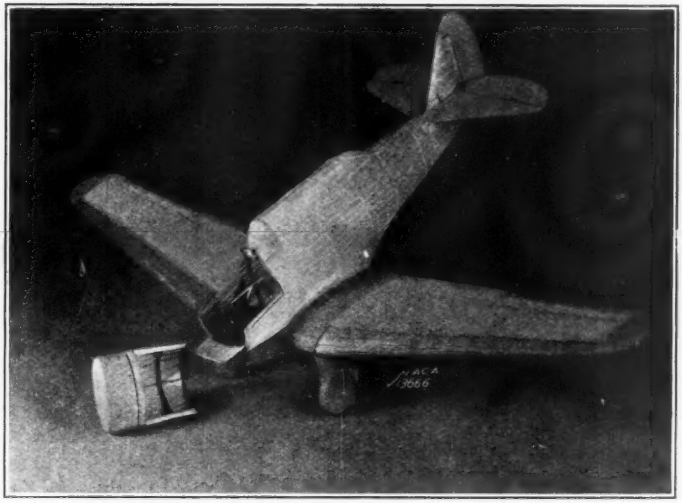


FIG. 18.

Model for the free-flight tunnel showing control operating mechanism.

trailing wire of sufficient length to remain slack and connected to the model operator's switches.

The procedure in a test run is somewhat as follows:—With model on the floor of the tunnel the angle is adjusted to about the expected value and the air speed is slowly increased. When flying speed is attained the model takes off and climbs, the speed and angle then being adjusted to attain steady flight in the centre of the tunnel. Meanwhile the " pilot " has had the sole task of maintaining the model laterally in the centre of the tunnel by use of the rudder. He then takes charge of the flight conditions and proceeds with the test schedule.

No extensive investigations have as yet been undertaken in this tunnel, although numerous model flights have been made in the course of the development work. To investigate the utility of the tunnel for direct study of the stability characteristics of an aeroplane, the model shown in Figs. 17 and 18 was fairly extensively tested. This model represented an existing aeroplane which was known to have certain unsatisfactory characteristics in its original form. Owing to the

low scale of the tests the investigation was largely confined to conditions away from the stall, although it was found possible to simulate the stalling characteristics of the aeroplane roughly by empirical adjustments of the filleting.

The first step was to consider the possible effect of longitudinal stability on the handling characteristics of the aeroplane by comparing the behaviour of the model with normal horizontal tail area and with the area increased 50 per cent. Briefly, it was concluded that the longitudinal stability characteristics did not appreciably affect the problem in this case. The remainder of the investigation was therefore directed to the effects of various combinations of dihedral and fin area on the flying qualities of the model.

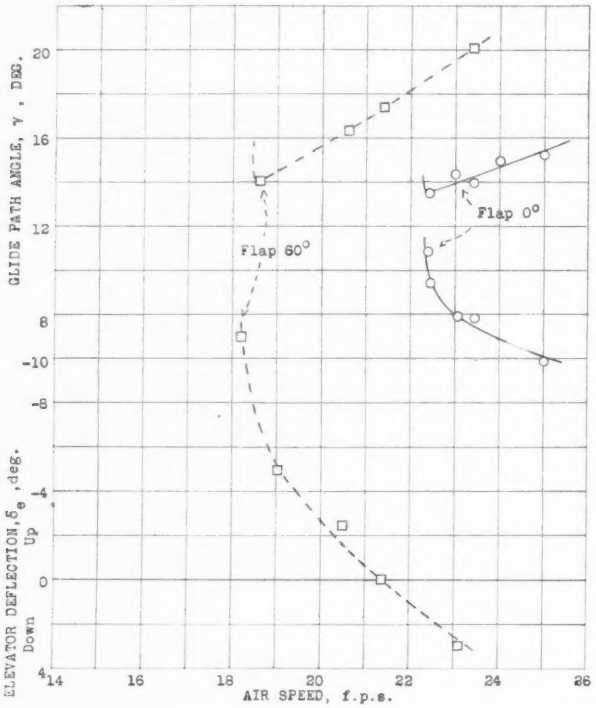


FIG. 19.

Glide path angle and elevator settings of the low-wing monoplane model in the free-flight tunnel.

Fig. 19 illustrates the type of data regarding glide path and control settings that can be directly obtained under steady flying conditions in the tunnel. Clearly the low scale of the tests leads to departures from the polar curves that would be expected for the full size aeroplane, but the qualitative effects to be anticipated, from the use of flaps for example, are clearly indicated.

The effect of the lateral stability characteristics was investigated by varying the dihedral angle and the fin area until the best relation based on the observed flying qualities was obtained. The results are shown in Fig. 20 plotted on the type of chart given in reference 24 for the calculation of lateral stability characteristics. The various combinations of fin area and dihedral, as well as observa-

tions on the flying characteristics are noted on the figure. The ordinates are equivalent to yawing moment per unit angle of sideslip and the abscissas to rolling moment per unit angle of sideslip, so that in general movement of a point upward on the chart corresponds to increasing fin area and movement to the right corresponds to increasing dihedral. The dash line in each case is drawn through the region in which the best flying characteristics were noted in the tunnel. It is interesting to note, in particular in the case of flaps neutral, how small a region of spiral stability lies between the regions on the one hand of spiral divergence, and on the other hand of lateral oscillations, or " Dutch roll," as they are sometimes called.

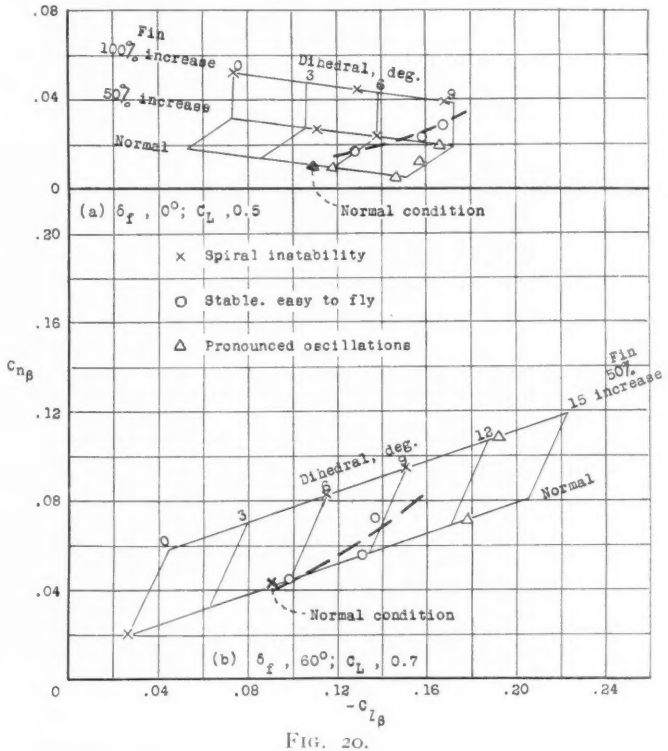


FIG. 20.

Lateral stability chart of the low-wing monoplane model in the free-flight tunnel.

Considering both the flap-up and flap-down conditions it appeared that an increase of fin area of about 50 per cent. and an increase of dihedral of about 2 degrees should be a good compromise for the aeroplane under consideration. Although no quantitative verification in flight has been undertaken, observations on the full-scale machine appear to substantiate this conclusion. A more satisfactory aspect of these results is the excellent qualitative agreement between the trend as to ease of handling found in the tunnel and the trend to be expected from theoretical considerations already well known. On this basis the free-flight tunnel appears to offer a useful, rapid, and relatively inexpensive means for the investigation and correction of the handling characteristics of new aeroplane designs.

As a result of the work here described, the Committee was sufficiently encouraged to undertake the construction of a larger free-flight wind tunnel having a throat diameter of 12 feet. This tunnel, contained in a large spherical steel shell, can be operated at several atmospheres pressure and will provide a means for extending the model research on stability and control to larger sizes and higher Reynolds number. An exterior view of the tunnel, which has been placed in operation within the last few weeks, is shown in Fig. 21.

Conclusion.

In the course of this lecture it has been my endeavour to show how the National Advisory Committee for Aeronautics, through the application of organised research on the problems of flight, has attempted to meet the needs of aeroplane design by the development of specialised research equipment. Where the Wright brothers led many men indeed have followed, and this new branch of human activity, still less than forty years old, has reached sufficient proportions to justify the prediction that it will never come to an end so long as

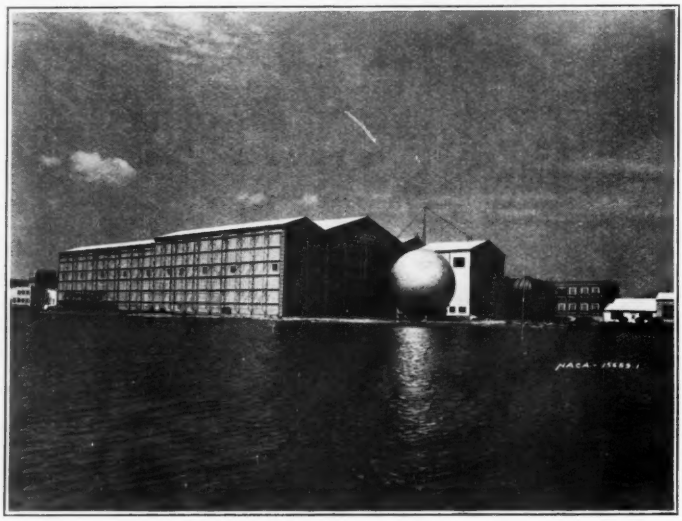


Fig. 21.
The N.A.C.A. free-flight variable density tunnel.

man is on the earth. Such progress as can be reported has been the result of much individual and collective effort, and in this conclusion I wish to acknowledge the sincere and whole-hearted co-operation not only of the men mentioned throughout this paper, but of the whole staff at Langley Field for their contributions to the N.A.C.A.'s share in this development.

It is my sincere hope that the work we have been able to carry on in the United States will prove of interest to our friends and co-workers in the field of aeronautics in England.

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THE PRESIDENT: As was well known it was not customary to hold a discussion of the Wilbur Wright Lecture, and therefore he proposed to conclude the proceedings by asking Mr. D. R. Pye, Director of Scientific Research at the Air Ministry, to propose a vote of thanks to the lecturer, which would be seconded by Mr. H. E. Wimperis, Past-President of the Society and the first Director of Scientific Research at the Air Ministry.

Mr. D. R. PYE (Director of Scientific Research, Air Ministry): He felt sure he was expressing the feelings of everyone present when he said that this was a very notable occasion. Most of the Wilbur Wright lectures were notable occasions but for several reasons particular interest attached to this one. It was the first time that a President of the sister Society, the Institute of Aeronautical Sciences in New York, had come over here to deliver the principal lecture of the year in this country. Incidentally, it was a matter of great satisfaction that this event coincided with the first occasion on which the Royal Aeronautical Society, after what he might describe as years of hotel life, was in the position to entertain the lecturer after his labours in its own home and in a manner worthy of him and of the Society. He expressed the hope that all those members of the Society who had not yet paid a visit to Hamilton Place would take an early opportunity of doing so and of being soothed by the atmosphere of elegant opulence which they would find there.

Continuing, Mr. Pye said that Dr. Lewis accepted the invitation to give this lecture in rather special circumstances. The Institute of Aeronautical Sciences recently established a Memorial Lecture in honour of the Wright Brothers and honoured the Royal Aeronautical Society and Professor Jones by inviting him to go to America and give the first Wright Brothers Lecture. He believed he was right in saying, although he had not had it directly from Dr. Lewis himself, that Dr. Lewis had already accepted an invitation to deliver the second Wright Brothers Lecture before he received the invitation to deliver the 27th Wilbur Wright Lecture in London, and that the arrangements already made in America were cancelled and other arrangements made in order that he might be able to accept the invitation to come to London. They all appreciated very much that evidence of the goodwill which existed between the two societies, and which had enabled them that evening to listen to such a fascinating and important account of the latest additions to the research equipment in the United States and the results which had been achieved with it. The lecture that evening had followed as an appropriate successor to the Wilbur Wright lecture delivered by his predecessor—Mr. Wimperis—seven years ago which dealt with new methods of research in aeronautics. He also wished to mention the pleasure which they all felt at having in the Society's records the extraordinarily interesting details which Dr. Lewis gave at the beginning of his lecture about the very early research programme and experiments of the Wright Brothers. Dr. Lewis had done the Society a peculiar honour in allowing it to have these as the first published record of that work.

It was a pleasure, also, to be able to speak of the very close and cordial relationship which existed between the staff at Langley Field under Dr. Lewis, and the scientific and technical staff under the Air Ministry in this country, and of the very great assistance which everyone in this country had received during their visits to America, and in particular from Dr. Lewis himself and Major Lester Gardner, one of the latest elected Honorary Fellows of the Royal Aeronautical Society. There was the greatest desire in this country to reciprocate in the fullest degree for the wonderful welcome which everyone from this country had received during their visits to America and he wished to say publicly that he would like to see this co-operation pressed to its farthest limits. That this country, within any time which was of interest at the present day, should find itself in armed conflict with the English speaking people of America was to him, and he believed to the vast majority of those present, utterly inconceivable, and the logical conclusion from that was that any restrictions on the interchange of scientific information which might arise from Government limitations might well be removed and that this interchange should be free and open without any thought on either side of a *quid pro quo*.

It was, continued Mr. Pye, unfortunate that the vagaries of ocean travel of the present day should have interfered somewhat with the arrangements made for the visit of Dr. Lewis and Major Gardner. When it was possible to fly the Atlantic regularly we would at all events not expect people to be 1½ days late. It was to be hoped that it would be possible for their visit to be extended correspondingly at the latter end, otherwise, strong men though they both were, he feared that the extra compression of their programme might involve a rest-cure when the time came for them to leave. Perhaps it was fortunate for the Society that the Wilbur Wright lecture had fallen at the very beginning of their visit, and also fortunate for Dr. Lewis and Major Gardner that the Whitsun holiday would come in the middle of it.

Mr. Pye concluded by expressing the great pleasure it gave him to move that a hearty vote of thanks be accorded to Dr. Lewis for his really delightful and fascinating lecture.

Mr. H. E. Wimperis (Past President) : It was with very great pleasure indeed that he seconded the motion which had been proposed by Mr. Pye, whose remarks in appreciation of the lecture he entirely endorsed. Dr. Lewis had mentioned a lecture which the speaker had given some seven years previously on new methods of research in aeronautics and it was remarkable to contemplate that all the new things which Dr. Lewis had told them about that evening had come to light in the short space of seven years. If anyone then had shown him, or if anyone more recently had shown him, a photograph of the huge spheres which they had seen that evening and asked him what they were, the last thing he would have guessed would have been that they were wind tunnels. However, they had the authority of Dr. Lewis on the point, which they would not doubt, that that was indeed what they really were. It was to be hoped that Dr. Lewis' strength would enable him to see all the things in this country which he was sure he would like to see.

Continuing, Mr. Wimperis said that the co-operation in respect of aeronautical research between the two Governments in the past had been really remarkable. That co-operation as a matter of fact, had been very close since the Great War when they were Associated Powers, and when they from this side had visited the United States all had been shown with the greatest readiness things which were of great help to them. At the same time, those in this country had done their best to reciprocate when they had been fortunate enough to receive visitors from the other side, and he hoped that would long continue. They were still Powers and he hoped they were still Associated!

He felt sure, he added, that this meeting would wish to send a cordial greeting to Dr. Ames, the Chairman of the National Advisory Committee for Aeronautics in the United States who used to come over to this country nearly every year and

whom it was a delight and a pleasure to see. He used to attend the meetings of their own Aeronautical Research Committee and take part in the discussions, and it was a great grief that they had not seen him over here for some years. He hoped, therefore, that Dr. Lewis, in the name of the meeting, would convey to Dr. Ames when he returned, an affectionate greeting from this side. As a small addition to that message he would be glad if Dr. Lewis would tell Dr. Ames that there had been an addition to his family and also to that of Sir Henry Tizard. The child that had been born was a child of the National Advisory Committee for Aeronautics and of the Aeronautical Research Committee. He referred to the Australian Aeronautical Research Committee now in course of formation. He hoped that infant would have a sturdy youth and he was sure that those in charge of it would look after its early training, and see that it was taught to read the blue-bound fairy stories issued by Sir Henry Tizard and the not less imaginative volumes bound in yellow which came from Washington. Everyone wished that infant complete success and he was sure that it, on its part, would do its best to do credit to a very distinguished parentage.

Before he closed, Mr. Wimperis referred to the last occasion on which he saw Major Lester Gardner, their distinguished Honorary Fellow. They were, he said, on a visit to Gottingen and had been to see Prof. Prandtl. It was at the end of a very hot day and Major Lester Gardner, he knew, was feeling that something ought to be done about it! He remembered very well walking along a street with him and Prof. Prandtl and passing a very fine town hall which incidentally, Major Lester Gardner had discovered had been converted into an inn. Major Lester Gardner tactfully drew attention to it in the hope that Prof. Prandtl would show them inside, but Prof. Prandtl, having other inclinations replied " Oh yes, it used to be interesting but now is a mere Bierhaus." However, on the present occasion when Major Gardner arrived at the new home of the Society after the meeting, he would find happier conditions.

The vote of thanks was carried with hearty acclamation and the meeting closed.

The Lecture was followed by the Annual Council Dinner. For the first time in the history of the Society the dinner was held in the Society's own home, at No. 4 Hamilton Place, The following were present:—

Guest of Honour, Dr. George W. Lewis, President of the Institute of the Aeronautical Sciences.
Lord Aberconway, Chairman of the Westland Aircraft Company Limited.
Colonel Abbott, F.R.I.B.A.
Captain P. D. Acland, Member of Council.

Mr. Bruce Ball, President of the Institution of Mechanical Engineers.
Professor L. Bairstow, C.B.E., F.R.S., F.R.Ae.S., Member of Council.
Major T. M. Barlow, M.Sc., M.Inst.C.E., M.I.Mech.E., F.R.Ae.S.
Mr. W. J. Binnie, M.A., President of the Institution of Civil Engineers.
Mr. R. Blackburn, Director of Blackburn Aircraft Limited.
Mr. H. C. Bradshaw, F.R.I.B.A.
Mr. Griffith Brewer, Hon.F.R.Ae.S. (Vice-President).
Sir Charles Bruce-Gardner, Chairman of the Society of British Aircraft Constructors.
Major J. S. Buchanan, C.B.E., F.R.Ae.S., Deputy Director-General of Production, Air Ministry.
Major G. P. Bulman, O.B.E., B.Sc., F.R.Ae.S., Deputy Director of Research and Development (Engines), Air Ministry.
Mr. L. F. G. Butler, Chief Designer of the Bristol Aeroplane Co. Ltd. (Engines).

Sir Edward Campbell, Bt., M.P., Parliamentary Secretary to the Rt. Hon. Sir Kingsley Wood, M.P.
Dr. H. Roxbee Cox, D.I.C., B.Sc., F.R.Ae.S.

Dr. C. G. Darwin, M.A., Sc.D., F.R.S., Director of the National Physical Laboratory.
Mr. Leo d'Erlanger.
Mr. W. C. Devereux, F.R.Ae.S., Member of Council.
Mr. D. L. Ellis, B.Sc., A.R.T.C., A.F.R.Ae.S., Member of Council.
Air Marshal Sir Wilfrid Freeman, K.C.B., D.S.O., M.C., Air Member for Development and Production, Air Ministry.
Mr. A. H. R. Fedden, M.B.E., D.Sc., M.I.A.E., M.I.Mech.E., M.S.A.E., F.R.Ae.S., President of the Royal Aeronautical Society.
Major Lester Gardner, Hon. F.R.Ae.S., Secretary of the Institute of the Aeronautical Sciences, Inc.
Mr. A. Gouge, B.Sc., F.R.Ae.S., Member of Council.
Professor F. T. Hill, F.R.Ae.S., M.I.Ae.E., Member of Council.
Professor G. T. R. Hill, M.C., M.Sc., F.R.Ae.S.
Air Vice-Marshal R. M. Hill, M.C., A.F.C., F.R.Ae.S., Member of Council.
Mr. E. W. Hives, F.R.Ae.S., Rolls-Royce Limited.
Mr. J. E. Hodgson, Hon. F.R.Ae.S., Honorary Librarian of the Society.
Mr. John Jay Ide, Technical Assistant of the National Advisory Committee for Aeronautics in Europe.
Professor B. Melvill Jones, C.B.E., A.F.C., M.A., F.R.Ae.S.
Sir W. Benton Jones, Bt., Chairman of the United Steel Corporation.
Lord Kenilworth, C.B.E., F.R.Ae.S., Chairman and Managing Director of Armstrong Siddeley Motors Limited.
Major D.H. Kennedy, O.B.E., F.R.Ae.S., Honorary Treasurer of the Society.
Mr. Percy Kidner, President of the Institution of Automobile Engineers.
Major McDonald, Assistant Military Attaché (for Aviation) American Embassy.
Colonel E. E. B. Mackintosh, D.S.O., Director of the Science Museum.
Major J. R. McCrindle, O.B.E., M.C., British Airways.
Major R. H. Mayo, O.B.E., M.A., Assoc.M.Inst.C.E., F.R.Ae.S.
Dr. N. A. V. Piercy, M.Inst.C.E., M.I.Mech.E., M.Cons.E., F.R.Ae.S.
Mr. R. K. Pierson, F.R.Ae.S., Vickers Aviation Co. Ltd.
Professor A. J. Sutton Pippard, M.B.E., D.Sc., M.Inst.C.E., F.R.Ae.S., Member of Council.
Mr. F. Handley Page, C.B.E., F.R.Ae.S., M.I.Ae.E., Member of Council.
Air Vice-Marshal C. F. A. Portal, C.B., D.S.O., M.C., Director of Organisation.
Captain J. Laurence Pritchard, Hon. F.R.Ae.S., Secretary, Royal Aeronautical Society.
Mr. D. R. Pye, C.B., F.R.S., M.A., Sc.D., M.I.Mech.E., F.R.Ae.S., Director of Scientific Research, Air Ministry.
Mr. E. F. Relf, F.R.S., A.R.C.Sc., F.R.Ae.S.
Colonel M. F. Scanlon, Assistant Military Attaché (for Aviation) American Embassy.
Mr. Gerald Steel, Samuel Fox & Co. Limited.
Lord Sempill, A.F.C., F.R.Ae.S., Member of Council.
Lt.-Col. Sir Francis Shelmerdine, C.I.E., O.B.E., F.R.Ae.S., Director-General of Civil Aviation.
Major B. W. Shilson, O.B.E., M.I.Mech.E., F.R.Ae.S., Assistant Director of Production, Member of Council.
Mr. H. O. Short, F.R.Ae.S., Short Bros. (Rochester and Bedford) Ltd.
Professor R. V. Southwell, F.R.Ae.S., Oxford University.
Sir Arthur Street, K.B.E., C.B., C.M.G., C.I.E., M.C., First Deputy Under-Secretary of State (Acting Permanent Under-Secretary of State for Air).

Rear-Admiral Sir M. F. Sueter, M.P., Chairman, Parliamentary Air Committee.

Air Vice-Marshal A. W. Tedder, C.B., Director-General of Research and Development, Air Ministry.

Mr. F. M. Thomas, A.F.R.Ae.S., Member of Council.

Mr. H. J. Thomas, F.R.Ae.S., Assistant Managing Director, Bristol Aeroplane Co. Ltd.

Sir Henry Tizard, F.R.S., A.F.C., F.R.Ae.S., Chairman, Aeronautical Research Committee.

G. R. Volkert, F.R.Ae.S., Handley Page Limited.

Dr. H. C. Watts, M.B.E., M.Inst.C.E., F.R.Ae.S., Member of Council.

Air Vice-Marshal W. L. Welsh, C.B., D.S.C., A.F.C., Air Member for Supply and Organisation.

Mr. H. E. Wimperis, C.B., C.B.E., D.Eng., M.I.E.E., F.R.Ae.S., Immediate Past President.

Mr. L. A. Wingfield, M.C., D.F.C., A.R.Ae.S.I., Solicitor to the Royal Aeronautical Society.

Rt. Hon. Sir Kingsley Wood, M.P., Secretary of State for Air (President of the Air Council).

Mr. R. T. Youngman, B.Sc., F.R.Ae.S., Member of Council.

EXPERIMENTAL RESEARCH IN THE GUIDONIA SUPERSONIC WIND TUNNEL.

By Lieut. Antonio Ferri.

(*Translated, by permission of the Lilienthal-Gesellschaft für Luftfahrtforschung, from* "Jahrbuch 1938 der Deutschen Luftfahrtforschung," *Ergänzungsband, and the Author, by Miss F. M. Buss.*)

Introduction.

Our first phase of activity, at the Guidonia supersonic wind tunnel, was devoted to studying and designing the necessary apparatus for carrying out systematic research. (See Captain Gasperi's paper, read before the Lilienthal Congress in 1937.) This apparatus consisted principally of:—

(1) A series of transformer jets, to create the requisite speeds in the test chamber;

(2) A balance, to determine the forces exercised by aerodynamic phenomena upon the objects under test;

(3) The striometric and interferometric apparatus.

The initial study was long and laborious; since we lacked the great help furnished by previous research, which is nearly always forthcoming in similar studies, we had to proceed by means of successive experiments until the apparatus took its final shape. Eventually we evolved a series of jets, a balance and an optical installation which we hope are permanent. These, however, being still under construction, have not yet been tested.

It may be interesting to mention the reasons that led to the adoption of the present scheme; reasons derived from experiments with temporary plant, some of which was still unknown when the research began.

Simultaneously, we started, with our makeshift equipment, systematic experiments in the sonic field, obtaining results that were concrete, interesting, and in some ways new. I will deal with these results after having described the new test apparatus.

Part I.

Test Apparatus; Transformer Jets.

The first problem we confronted was how to construct transformer jets through which supersonic speeds could be obtained. These jets may be divided into two kinds, which should be studied separately: the *effuser* and the *diffuser*.

Whilst there were definite rules for the design of the former, such details were to a great extent lacking for the diffuser, which is the most delicate part of the jet. As Captain Gasperi's preliminary work, when in charge of the Guidonia wind tunnel, had given us some idea of how to construct a fairly good diffuser, we preferred to concentrate on the effuser, until we had obtained an apparatus that exactly fulfilled its purpose, rather than devote ourselves to a complete solution of the second problem.

In studying effusers we thought it better to work all the time with rigid jets, not attempting at first to experiment with elastic walls, although such walls had been studied and designed from the beginning. We were not yet in a position to define how nearly the elastic jet should follow a theoretical form (*i.e.*, what degree of elasticity should be given to the jet itself), and we did not wish to embark upon such a complicated construction, with the risk of failure.

We consider, however, that elastic walls might be very useful for the diffuser, where as there are no hard-and-fast constructional data, it might be advisable to make considerable alterations in the profile.

For our study of effusers, we undertook the construction of a series of jets with different Mach numbers (M.n.), based on the assumption that velocity was evenly distributed in the narrow part of the jet, and that its intensity and direction were constant along the whole of this section. Starting from this hypothesis, and designing the first part of the effuser in such a way as to have a gradual expansion, we obtained the next part of the jet itself by means of the method of characteristics.

Having constructed these jets, however, we frequently found that the M.n. obtained was less than had been expected; and sometimes, when noting the pressure, we found that, just after the critical section, there was a shock, which caused the behaviour of the pressure to differ from what had been calculated.

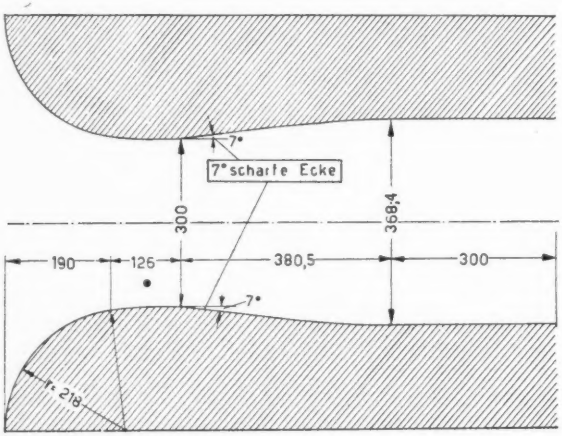


FIG. 1.
(In frame) 7° corner angle.

After careful study, this phenomenon led us to surmise that the hypothesis of constant speed in the critical section was incorrect; and in fact a few tests showed that in this section the velocity in the centre differed from that at the ends. Therefore we had either to modify the jet in the supersonic region, so as to have constant velocity in the critical section, or to take into account when designing it the true pressure distribution in this section.

At first we preferred the former system, and kept on modifying the experimental jets. But we consider that better results will be obtained by allowing for the distribution of velocity in the critical section. Consequently we are now experimenting in this direction, although the other system has given good results.

Since the most disturbed part of the jet and the most difficult to construct was that in which the walls were convex in the direction of the velocity (*i.e.*, the part which did not derive from the method of characteristics), we decided to study a jet invented by Captain Gasperi, which does away with this portion, replacing gradual expansion after the critical section by expansion around an edge (Fig. 1). By this means the whole jet can be designed in conformity with the basic method of characteristics.

This jet is somewhat shorter than the others, and does not present any technical difficulties, once the distribution of velocity in the critical section is known.

Experiments are now being made in order to determine the distribution of velocity in the critical section, after which the jet will be constructed.

Simultaneously with the supersonic jets we have constructed sub-sonic jets, which I will discuss when speaking of the experiments made with them.

BALANCE FOR DETERMINING FORCES.

In studying the balance, we had to decide three fundamental questions:—

(1) Whether or not it was advisable to put the whole machine into the low-pressure chamber of the wind tunnel.

(2) On what principle the elements of measurement should be based.

(3) How the aerodynamic forces should be analysed, and what scheme to adopt in the analysis.

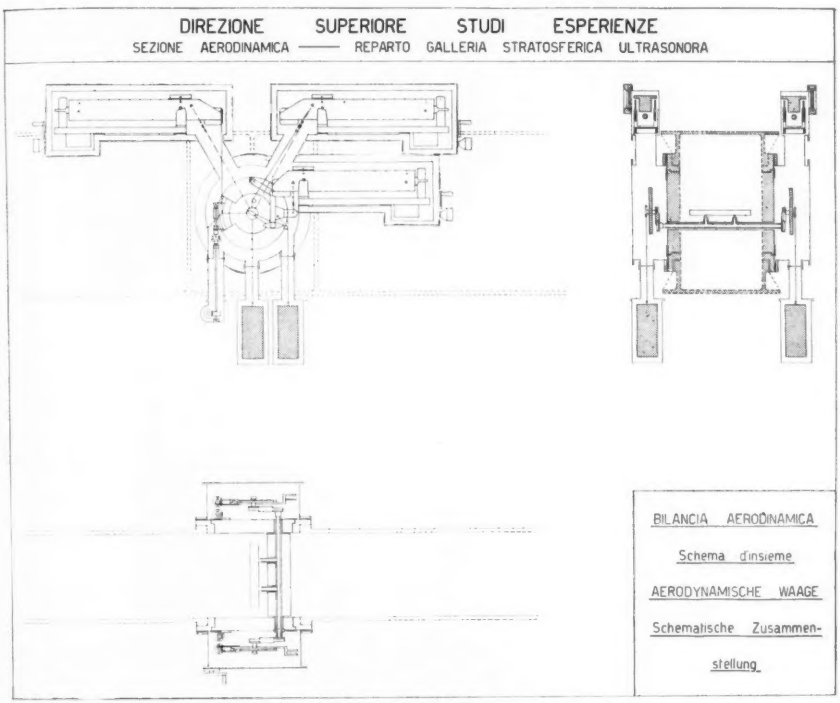


FIG. 2.

Aerodynamic balance: general diagram.

To guide us in these problems we constructed several temporary balances, which in general were only able to give two components of the aerodynamic force, and which did not allow of varying the angle of incidence of the model during the experiments. (That is why we only made experiments in the subsonic field, where it was at least possible to vary the speed gradually.)

The first balances were based on the principle of enclosing the whole measuring apparatus in the low-pressure chamber of the wind tunnel. The elements of measurement were of various types; at first we used dynamometric gauges, later spring gauges (see Captain Gasperi's paper, read before the Lilienthal-Gesellschaft, 1937). But these systems gave rise to many difficulties, especially as they

required frequent and difficult calibration; furthermore, being makeshift apparatus, it had not been brought to the point of perfection.

After various unsatisfactory attempts, we decided to use a double parallelogram balance, measuring directly by means of weights. This balance, which was one of the earliest that had been used in the former aerodynamic laboratory of the Italian Air Ministry, was too large for insertion in the low-pressure chamber and had necessarily to be fixed outside. The test wing was fastened to the balance by means of faired rigid bars, as in the case of the other balances. Airtightness around the rigid bar which transmitted the aerodynamic forces to the balance

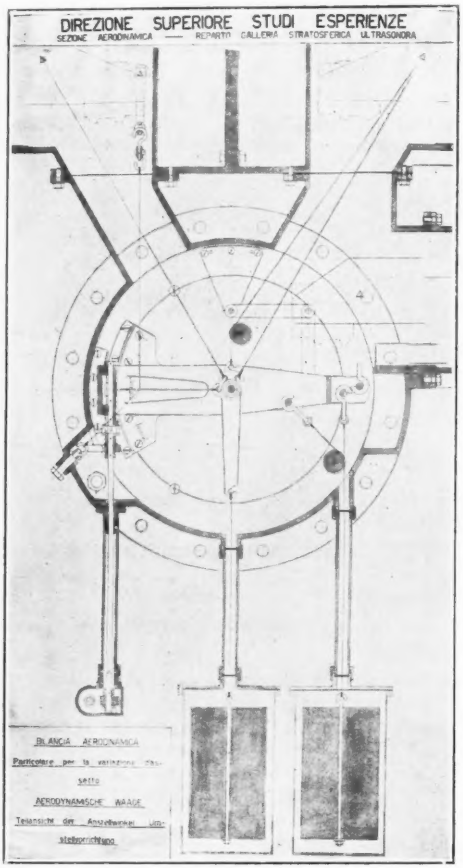


FIG. 3.
Aerodynamic balance: detail, showing device for varying the angle of incidence.

was obtained by means of spring compensators. Since a number of the experiments which I am about to describe were carried out with this balance, I will mention it again when speaking of the results obtained.

With this balance we were able to make experiments in the subsonic field, even in considerably disturbed zones; consequently we decided to adopt the system of measurement by weights, when constructing the permanent balance.

As, however, there were considerable difficulties in transmitting aerodynamic force from the model to the outside of the tunnel, owing to the necessity of keeping the apparatus airtight (any form of spring was inadvisable, owing to the lengthy and frequent calibration it entailed), we decided to construct a balance which would work at the same pressure as that of the test chamber.

The next problem was what system to adopt for transmitting to the scale the forces acting on the model.

In making this decision we took into account the following points:—

Calibration of bars and other supports, at the speeds obtained in the tunnel, is extremely difficult; sometimes, if interference phenomena intervene, impossible. It is therefore advisable to reduce this calibration to a minimum, and to have as few members of the balance as possible exposed to the wind.

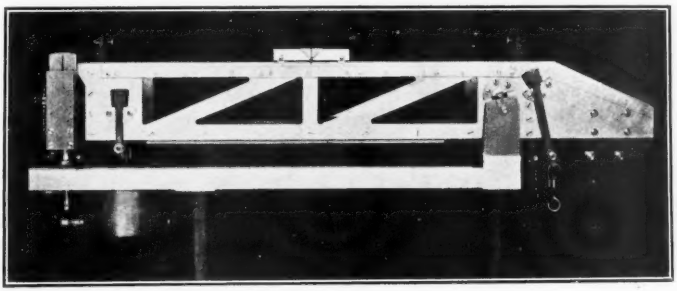


FIG. 4.

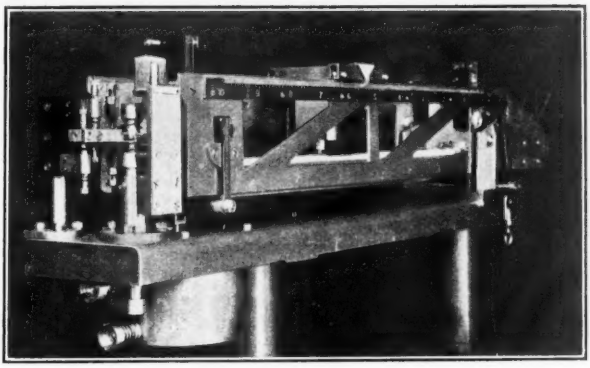


FIG. 5.

The simplest way of doing this was apparently to transmit the resultant aerodynamic force, by means of its two components, out of the flat sides of the tunnel, and to place the whole balance at this point, closed in an airtight case. In this way (Fig. 2) the balance is composed of two separate parts; consequently there must be six measuring gauges, in order to determine the three main components (*i.e.*, lift, drag, and longitudinal moment); but it is possible to measure also the pitching and rolling moments, and calibration is reduced to a minimum.

If the wing under test stretches right up to the walls, it is fastened by the wing-tips to each wall, so that only the model itself is exposed to the wind. If its span is less than the diameter of the tunnel, it is fixed by one or two faired

supports to a cross bar (also faired). When the angle of incidence of the model is varied, the supports swivel, so that they always present minimum resistance to the wind. The fairings (which in the diagram appear clumsy) have been reduced to a minimum, and we have evolved a series of them, for various types of model and for different speeds.

Two devices were used for analysing into its two components the force transmitted to the end of the support. The first (Fig. 3, dotted lines) enabled us to measure with precision the lift and the moment of bodies that have only a small lift. For this, it is unnecessary to have fixed points, which are hard to obtain, owing to the extreme variations of temperature in the all-metal test chamber. The second, or ordinary design, was used for models with normal lift.

The variation of angle of incidence was carefully studied, until we found a means by which one single control could turn the sector where the model was fixed in two directions. The measuring elements (Figs. 4 and 5) consisted of sliding weights, moved by small continuous current electric motors. The latter could be controlled either by the weight itself, as it shifted from its position of equilibrium, or, in case of violent oscillations, by the operator from outside.

The sliding weight can balance 10 kgs. With the addition of two other weights (which can be added from outside during the experiment), as much as 30 kgs. can be balanced.

The system of automatic contacts and the device for blocking the apparatus and for adding the extra weights are clearly shown in Fig. 5.

The whole balance is enclosed in a solid case, which is easily removable, so that the model can be rapidly dismounted, and each separate part of the apparatus can be inspected if necessary.

Measurements are made by direct readings from the scale, through glass panes.

Optical Apparatus.

We have designed for our supersonic wind tunnel a striometric and an interferometric apparatus.

The permanent striometric apparatus is now under construction, but the interferometer is still being studied. Before drawing up the final designs, we are waiting to see how the striometer works, so as to gather the necessary data for the other apparatus.

In designing this plant, which was done by the National Institute of Optics, several difficulties were encountered. The worst was vibration; since the tunnel was of metal throughout, and was firmly coupled to the compressor and to the continuous current motor, vibrations were inevitable.

These, even when of minimum amplitude, cause considerable disturbance, especially in interferometric observations.

We at first thought of placing the whole apparatus on a rigid beam, with supports independent of the foundations of the tunnel. This would have prevented vibrations from being transmitted to the apparatus. But in this case we would have had to fix the test wing in such a way that it was independent of the tunnel and remained immobile when the latter vibrated. The solution, even if possible, would have been complicated; hence we thought it better to fix the optical apparatus and the model rigidly in the tunnel. In fact, if the supports are robust and the whole apparatus is light and compact, as the model and optical apparatus are fixed in the same part of the tunnel their vibrations should be synchronised, and all relative motion between the two elements abolished; this being the factor which must be eliminated, in order to obtain satisfactory results.

Consequently we adopted the scheme shown in Fig. 6. The two convex lenses, 350 mm. in diameter, with a focal distance of one metre, are fixed rigidly to the tunnel, and are mounted in such a way as to form a perfect continuation of the metal walls. Hence they do not give rise to local disturbances, but help to keep the tunnel airtight. For this reason they are fairly thick, as they have to resist

a pressure equivalent to four atmospheres. As a source of light we had two alternative devices—an ordinary incandescent lamp, and a mercury lamp.

The apparatus can be perfectly regulated by means of a series of micrometric adjustments. Its rigidity is a guarantee of the satisfactory working, without the necessity of frequent inspections, and without having to adjust it each time.

Part II.

Results of the Experimemnts.

The most complex question, when experimenting in the supersonic field, is how to construct the test chamber. Given the small dimensions of the tunnel, it is extremely hard to make certain that the aerodynamic phenomena produced are identical to those which would occur if the object under test were moving at the same speed through still air.

If the current flows past rigid walls, the fact that, owing to the presence of the wing and to its thickness, the effective cross section of the test chamber is less than the sections preceding it, gives rise to an increment of speed throughout

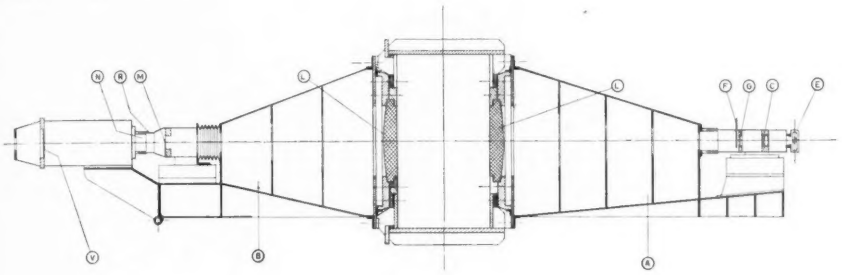


Fig. 6.

Diagram of the striometric apparatus.

L_1, L_2 *plane convex lenses*; $f = 1{,}000$ *mm.*
A, B, supporting brackets of apparatus.
N, screen.
R, extension tube.
M, Foucault diaphragm.
V, opaque glass.
F, regulating aperture.
G, filter for monochromatic light.
C, condenser.
E, source of light.

the section, in the subsonic field. The aerodynamic phenomena therefore differ from those which would be produced in the case of an object moving in an indeterminate fluid.

This alteration may be considerable, if the wing is large compared with the test chamber, and if the speed approaches closely to that of sound. These conditions are represented in Fig. 7, which shows the Mach numbers (M_2) in the section of maximum thickness of the wing, as a function of those (M_1) that are found ahead of the leading edge.

In calculating the results given in this graph, we merely took into account the fluctuations in speed deriving from the variations in cross section due to the obstacle of the wing, independently of the aerodynamic behaviour of the wing itself. We assumed the hypothesis of an adiabatic transformation, and of constant speed over the whole section. We considered various values of maxi-

mum wing thickness, which is given as a percentage of the diameter of the tunnel section, the latter being taken as circular.

If an incidence is given to the wing, especially when it spans the tunnel, noticeable and diverse variations of section occur at the two points where the tunnel is divided by the wing, creating speed gradients which are quite different on the upper and the lower surface.

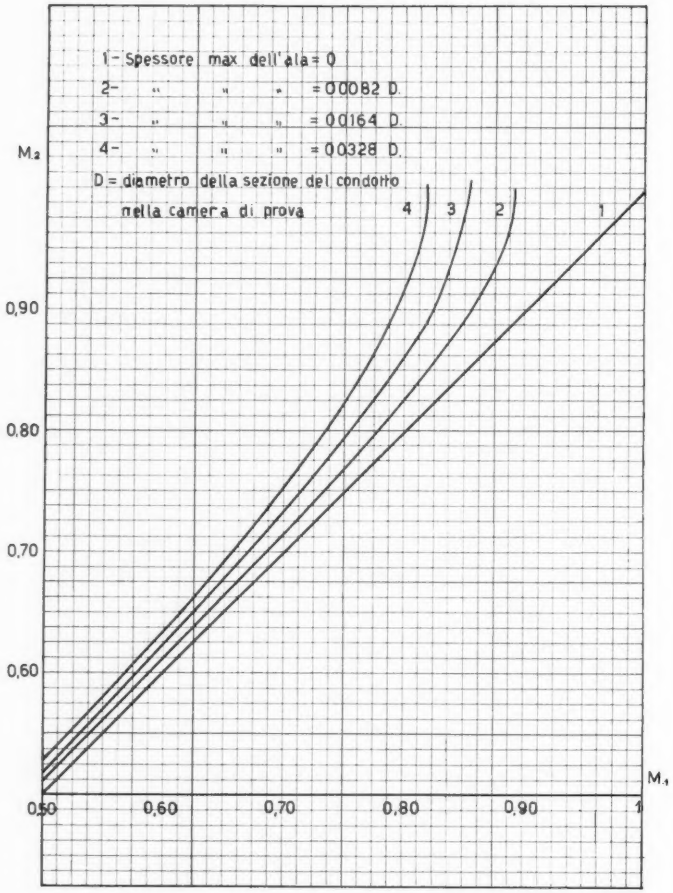


FIG. 7.

1. *Maximum thickness of the wing.*
D = diameter of cross section of the jet in the test chamber.

If the jet has a free flow (*i.e.*, surrounded by stationary air), these difficulties can be very largely eliminated; but if the aerodynamic phenomenon is not strongly localised and the outer parts of the current are also noticeably affected by it, then, due to the fact that the stationary air surrounding the current does not react upon the adjacent layers as if it were in motion with the rest, the aerodynamic behaviour of the object is not that which it is desired to study, and the phenomena in the tunnel may be very different from the real ones.

We consider, however, that to substitute for strata of infinite inertia around the current (as in the case of a flow surrounded by rigid walls) strata of no inertia at all (as in the case of a free flow), gives divergences less than the real ones, especially if the dimensions of the test wing are reduced to the minimum possible. Therefore, contrary to the practice elsewhere, we have chosen the second method, and have specially constructed two tunnels capable of creating a jet with free flow, for measuring forces and determining pressures respectively.

DESCRIPTION AND CHARACTERISTICS OF THE JETS.

The two jets planned by us differ only in their dimensions. The first, used for measuring forces, is smaller than the other. They have the following characteristics :—

(1) The cross section is rectangular and not circular. Thus it is easy to ensure the homogeneity of the current along the entire span of the wing under test; which is much more difficult with a circular tunnel, especially if the wing is comparatively large and stretches right across it.

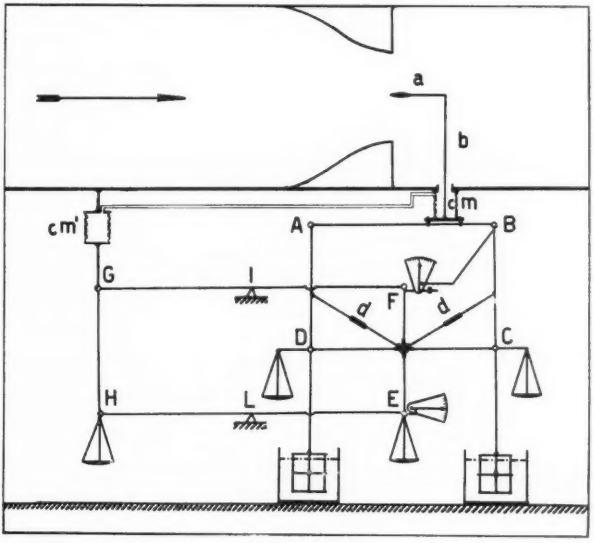


FIG. 8.

(2) Their profile is as illustrated in Fig. 8, *i.e.*, they consist of two walls which converge in an abruptly truncated choke, planned in such a way as to minimise the disturbances due to centrifugal force. The two walls are flat and continue beyond the point where the choke is truncated. Consequently the airflow may be regarded as moving in a flat plane.

The first jet constructed generates a current of 40×28 cm. cross section. The former dimension represents the distance between the rigid walls, and is equal to the span of the wing under test. A current of 40×50 cm. is generated by the second jet.

Before beginning the experiments we tested the regularity of the current, which proved satisfactory.

To this end we determined the behaviour of the static pressure along the three principal axes, *i.e.*, along the axis of the jet; along a horizontal axis perpendicular

to the first and situated where the leading edge of the test wing would come; and along a vertical axis perpendicular to the other two.

Some of these measurements are shown as graphs (Figs. 9, 10, 11). These give, for various positions the ratio; dynamic pressure upwind of the jet; static pressure as read in the test chamber; from which the M.n. can be deduced.

At the same time we determined the value of the dynamic pressure in the test chamber, for various M.n. These measurements, which were extended to

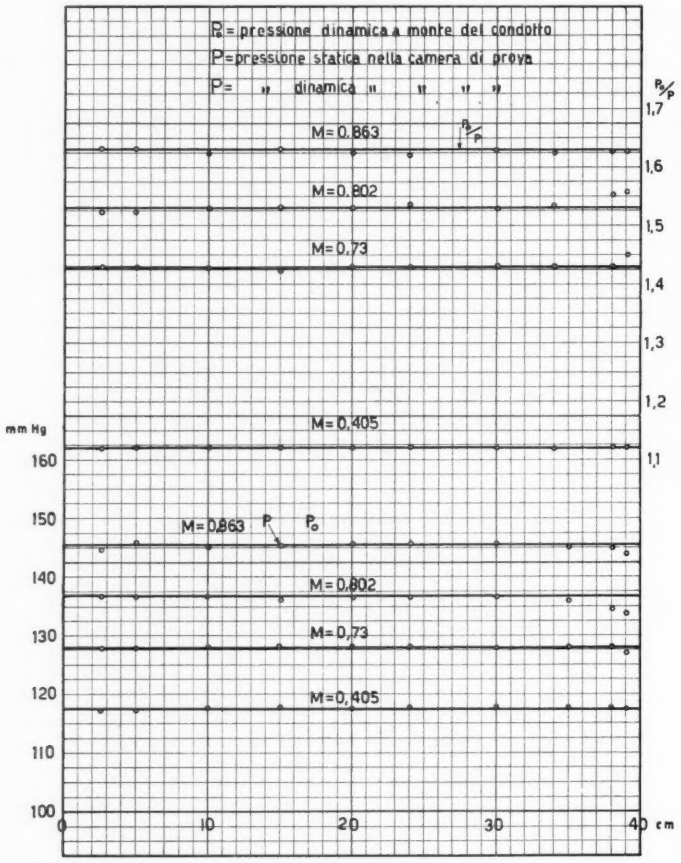


FIG. 9.

p_0=dynamic pressure upwind of the jet.
p=static pressure in the test chamber.

M.n.'s very near to 1, showed that the pressure is always practically the same as the dynamic pressure upwind of the jet, where the speed of the current is minimum; thus guaranteeing that adiabatic transformation takes place in the jet, and enabling us to check the accuracy of the calibration formula for the pitot tube in the sonic field.

Some of the readings are shown in Fig. 9, where the small circles represent the values of dynamic pressure in the test chamber, and the horizontal grid line

represents the dynamic pressure up-wind of the jet. After taking measurements in the empty chamber, we started tests on the wing itself, during which we checked that, within the limits of the field, the static pressure was not affected by the aerodynamic phenomenon created by the wing, and that in the direction of the axis of the jet, the value of this pressure was constant in the sections above and below the wing.

In the measurements of forces, which were made with a wing of 40 mm. chord in a jet 280 mm. high, the static pressure thus measured was not perceptibly influenced by the aerodynamic phenomenon of the wing, at speeds which very nearly approached that of sound.

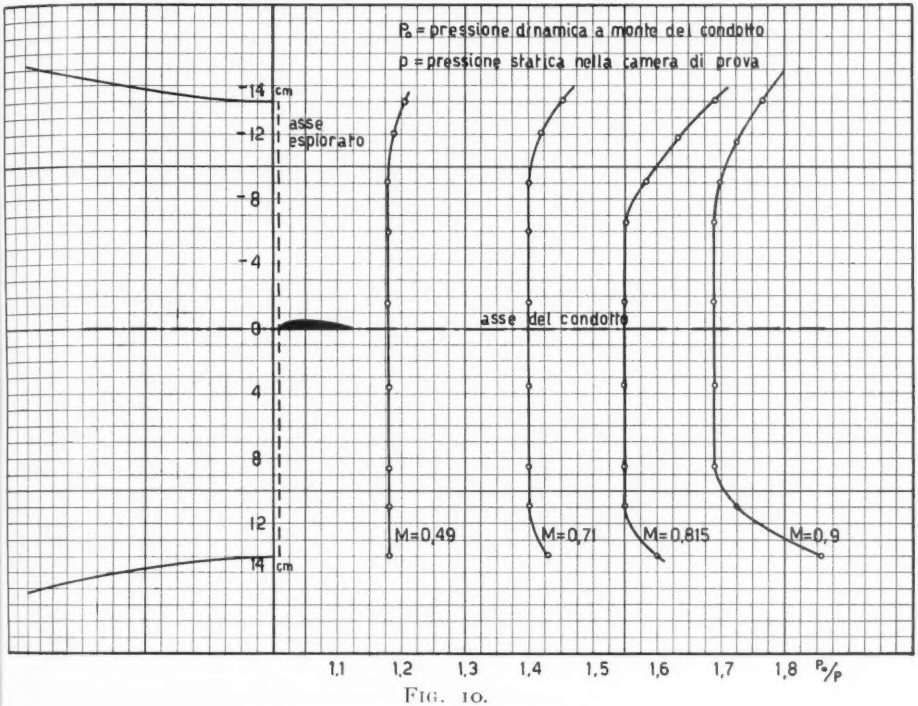


FIG. 10.

(Asse esplorato) axis investigated.
(Asse del condotto) axis of the jet.

For pressure measurements executed with a wing of 90 mm. chord, using the 280 mm. jet, we were obliged to stop below M.n. = 0.8, and with the 500 mm. jet we could not reach a velocity corresponding to 0.9 times that of sound, without the constancy of pressure being affected.

CARRYING OUT THE EXPERIMENTS.

With the jets described we determined, for various angles of incidence and at various speeds, the lift and drag characteristics of the wing profile shown in Fig. 12 (this being a profile used by the Italian Air Ministry when designing airscrews), and studied the distribution of pressure along the chord.

Forces were measured on a model wing of 40 mm. chord and 2.5 mm. maximum thickness. These were the smallest dimensions practicable, as we particularly

wished to reduce the size of the model as much as possible, in order to minimise the effect of the walls.

The wing was cut from a steel blade and was adequately strong; only at very high speeds and high angles of incidence did it bend slightly at the tips.

This little wing was tested in the first jet. It will subsequently be tested in the second, so as to have an idea of the effect of the walls and to compare the results.

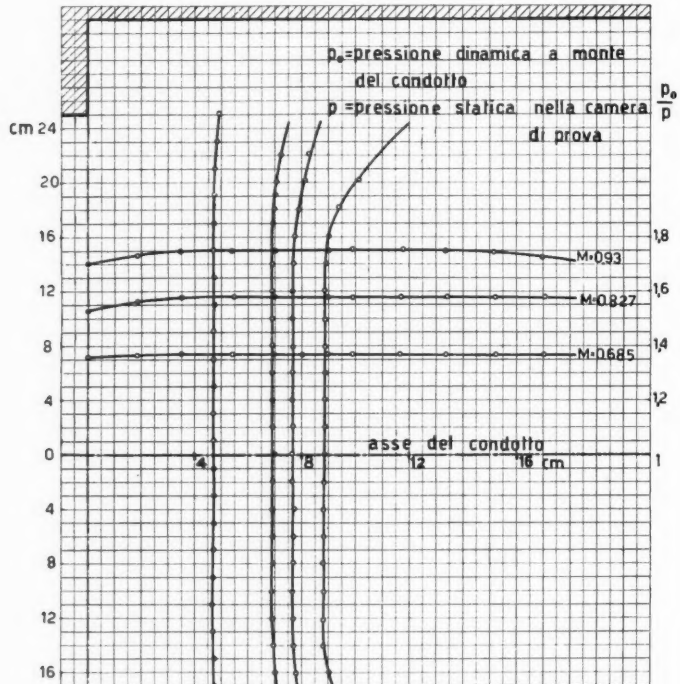


FIG. 11.

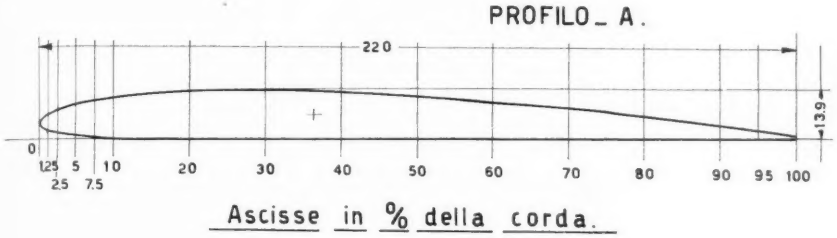
The forces were determined by means of a double parallelogram balance (Fig. 8). The wing is fixed on two faired arms *a*, which enable its incidence to be changed when not in motion.

These arms are fixed to two robust supports *b*, also faired, coupled to a single base *c*; the latter emerges from the tunnel and is connected to the balance. This machine, which is completely pivoted on knife-edges, allows lift and drag measurements to be taken, by means of its two parallelograms. The measurements are taken in succession, one of the parallelograms being fixed for each series. Fixing is effected by means of the diagonals *d*.

Airtightness around the arm c is obtained through an extremely elastic absorber, cm, one side of which is fixed to the wind tunnel and the other to the balance. To eliminate the friction (*Italian* tara) due to pressure upon this, a compensating body cm' with the same pressure jump is placed symmetrically opposite. At the beginning and end of each test we check up whether the pressures upon the two absorbers cancel each other out, even when there is an intense vacuum in the tunnel.

The absorber cm gave rise to a slight loss of sensitiveness in the drag measurements; this, however, was negligible in comparison with the size of the measurements. All supports were faired, and their resistance (*Italian* tara) represented about one fifth the minimum resistance of the wing.

Pressure measurements were made by constructing a steel wing of 9 cm. chord, through which were bored tubes of 1 mm. diameter, connecting with pressure heads on the surface of the wing. These were arranged along the wing span in such a way as to eliminate mutual interference.



X		0	1.25	2.50	5.0	7.5	10	20	30	40	50	60	70	80	90	95	100
y_2	in %	2	3,2	3,8	4,55	5,05	5,4	6,2	6,32	6,0	5,52	4,85	3,97	2,92	1,75	1,05	0,2
y_1	corda	2	1,12	0,87	0,55	0,30	0,15	0	0	0	0	0	0	0	0	0	0.10

FIG. 12.

Abscissæ as a percentage of the chord.

The wing tips were fixed to two discs incorporated in the tunnel walls. By rotating these discs the angle of incidence of the wing could be altered.

A multimanometer was connected with the jets, and measurements were made photographically.

Measurements of forces were taken at Reynolds numbers of approximately 180,000. This value was not constant in all the experiments but varied slightly, since the measurements were made at varying speeds with constant incidence.

The tests were repeated several times with higher Reynolds numbers (up to 250,000 for small angles of incidence), without any noticeable variations.

Pressure measurements were taken at much higher Reynolds numbers (round about 500,000).

Speeds were calculated from the pressures, assuming an adiabatic expansion.

RESULTS OF THE DETERMINATION OF AERODYNAMIC FORCES.

Graphs Nos. 13, 14, 15 and 16 give a resumé of the results obtained from the measurements of forces.

From these we can derive the following conclusions (see also my Report to the Aerotechnical Meeting at Naples of the A.I.D.A., May, 1938).

(1) The lift coefficient, calculated according to the formula:—

$$C_L = L/\tfrac{1}{2}\rho V^2 S$$

grows with the angle of incidence as the M.n. increases, up to a certain value of M.n. Its behaviour closely follows the theory enunciated by Prandtl and Glauert (Fig. 13).

(2) The value of M.n. above which the behaviour of C_L ceases to follow the Prandtl-Glauert law diminishes, as was anticipated, with the increase of incidence of the wing relative to the direction of the wind (see Pistolesi, Volta Meeting, 1935).

(3) At high angles of incidence, approaching those at which, for low speeds, the profile reaches its maximum lift, we find (Figs. 13 and 14) that the lift begins to drop for relatively low M.n., confirming (up to M.n. = 0.8) that the value of C_L max. and of the corresponding critical incidence decreases with the increase of M.n. (see Pistolesi, Volta Meeting, 1935).

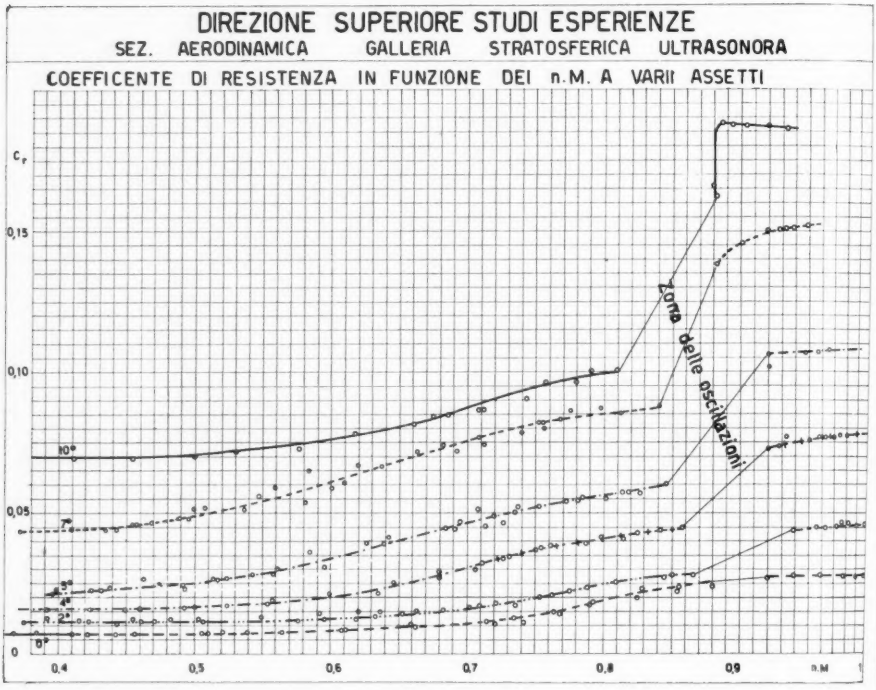


FIG. 13.

Lift coefficient as a function of M.n. at various angles of incidence.

(4) After the C_L curves have ceased to follow the Prandtl-Glauert theory, they reach a maximum, above which the value of C_L tends to diminish (Fig. 13).

At this point, after C_L has dropped for a while with increase in speed, wing flutter begins; the aerodynamic force varies so rapidly and violently that no measurements can be taken.

With further increase in speed, the region of instability is passed and the flutter ceases.

We then find very high values of C_L, especially at high angles of incidence.

If the velocity is further augmented until the speed of sound is almost reached, the values of C_L remain almost constant (Fig. 13).

(5) The angle of zero lift remains invariable up to M.n. of approximately 0.6 and the space increases up to values of M.n. between 0.7 and 0.8, as had been foreseen.

(6) For high M.n. we find that, within the field of our experiments, the incidence of maximum lift has not been reached (Figs. 14 and 15).

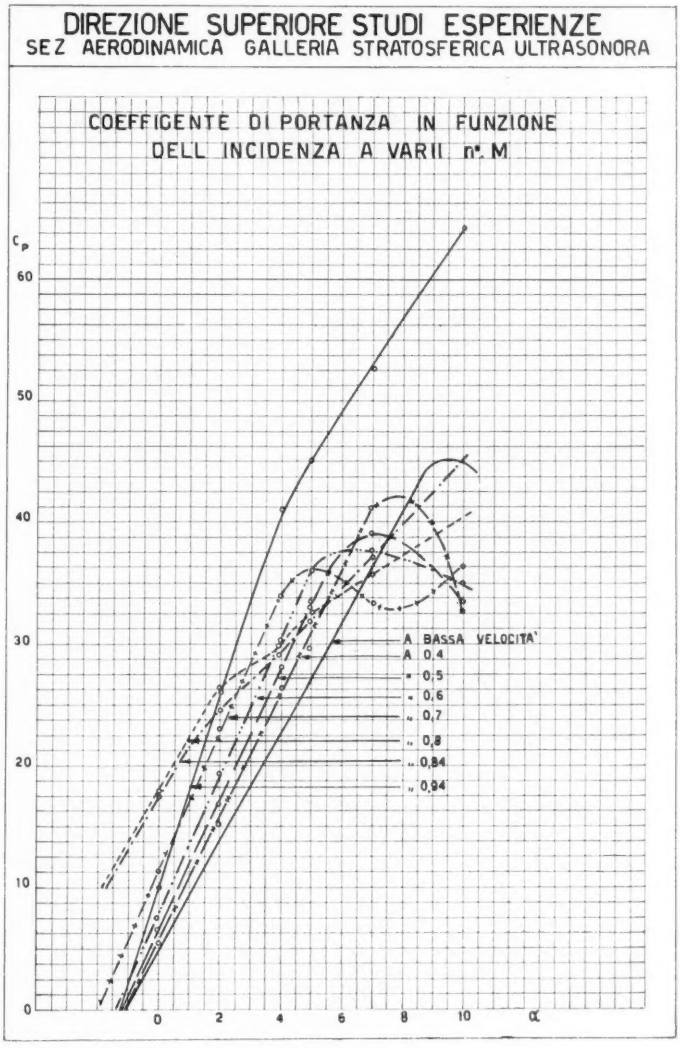


FIG. 14.

Lift coefficient as a function of the incidence at various M.n.

This phenomenon is peculiar and, although the optical results seem to bear it out, requires further confirmation.

(7) The maximum efficiency of the profile (Fig. 16) grows with the increase of M.n., reaching a maximum between 0.5 and 0.6, after which it tends to diminish. For values of M.n. above 0.8 the diminution is marked.

(8) The behaviour of C_D (Fig. 16) ($C_D = D/\frac{1}{2}\rho V^2 S$) corresponds to that of C_L. It is noteworthy that the curve, which at first is flat, rises gradually for a while, without the enormous increases which other experimenters have found between

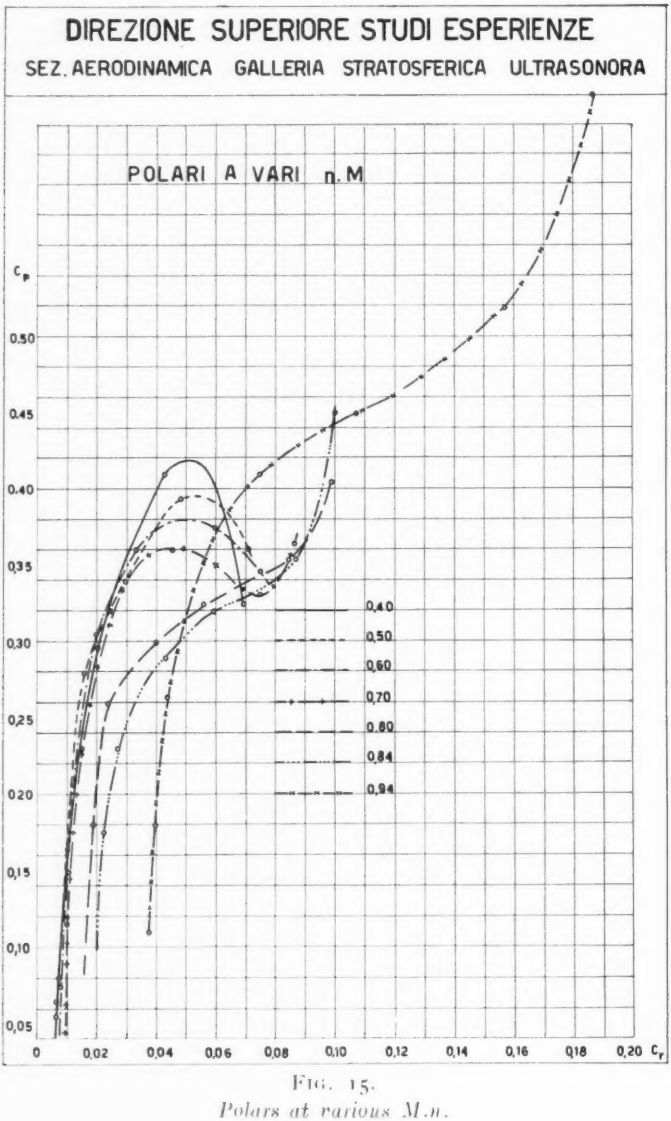


FIG. 15.
Polars at various M.n.

M.n. 0.6 and 0.8, and which have made them speak of a concrete "sound barrier."

In the flutter zone C_D increases considerably for high angles of incidence, and beyond this region it stabilises itself at a practically constant value.

This increase diminishes with decrease in the angle of incidence, and at low incidences the behaviour of C_D agrees even quantitatively with that of similar profiles, as discovered when experimenting with airscrews (see Douglas, Volta Meeting, 1935).

It is also worth mentioning (Fig. 15) that the increase in drag due to increase in M.n. is almost constant, and for fairly low values of C_D it is independent of C_D and consequently of the angle of incidence.

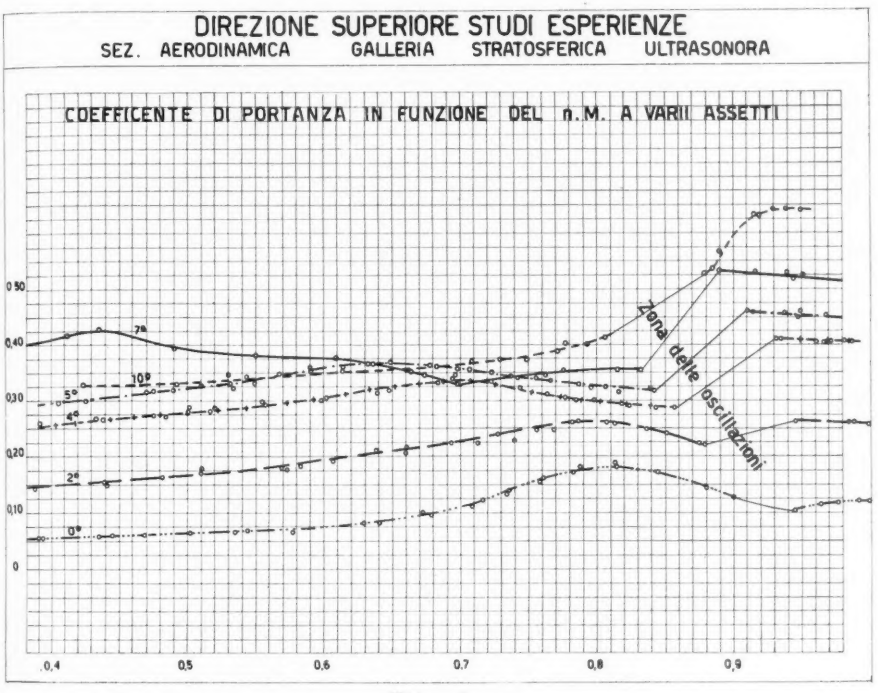


FIG. 16.

Drag coefficient as a function of M.n. at various angles of incidence.

RESULTS OF THE OPTICAL RESEARCHES.

Simultaneously with the measurements of forces, we made optical studies with our provisional apparatus. These led us to the following conclusions:—

(1) At the M.n. at which C_L detaches itself noticeably from the theoretic law, there appears the first sign of a shock wave on the upper surface of the wing. (Fig. 17)

If the incidence of the wing is small, a corresponding wave appears on the under surface, slightly farther back than the first.

(2) As the speed grows, the wave goes on spreading and becoming more accentuated, and if the lighting is good, one can see a wake, becoming steadily clearer, which originates behind the wave on the upper surface of the wing. (Fig 18)

(3) With still further increase in M.n., after the first shock wave has grown considerably and has moved slightly backwards, a second shock wave appears behind it, which as the speed increases becomes definitely marked. This wave

does not touch the upper surface of the wing, but stops at the vortices of the wake behind the first wave (Fig. 19)

(4) At still higher speeds the first wave spreads and tilts, the second tends to move forwards, until eventually the two waves meet. (Fig. 20)

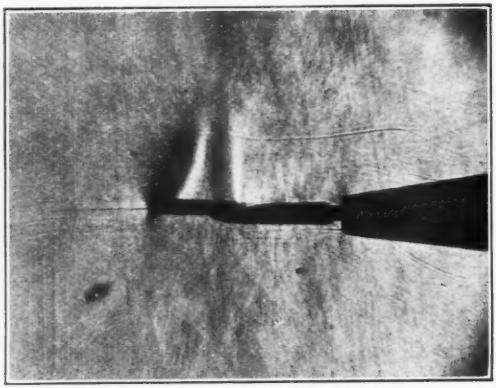


FIG. 17.
$a = 0^{\circ} - n.M. = 0{,}85$.

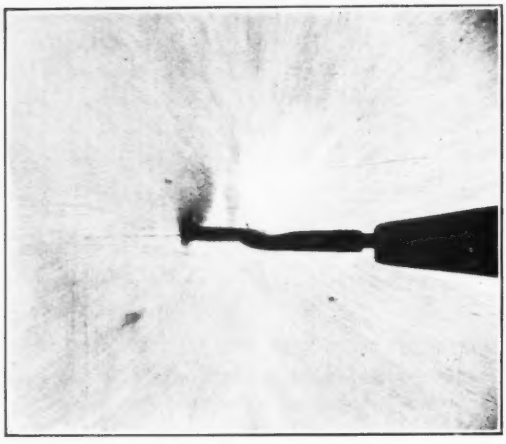


FIG. 18.
$a = 0^{\circ} - n.M. = 0{,}80$.

This point marks the beginning of the flutter zone, which is quite visible optically: the two waves are no longer fixed, but the first oscillates backwards, while the second oscillates towards the first.

(5) When the flutter zone is passed, the two waves appear quite definite and separate; the front wave is the first to settle down, while the second wave still oscillates for a while at the tip.

The first wave has moved a long way backwards, has spread considerably, and has a noticeable tilt. The second wave has also moved backwards, till it is beyond the trailing edge of the wing; it still stops short where it meets the wake of the first. Besides the two waves on the upper surface, when the flutter zone is passed, there appears, at all angles of incidence, a shock wave on the lower surface, corresponding to the second upper wave. (Fig. 21)

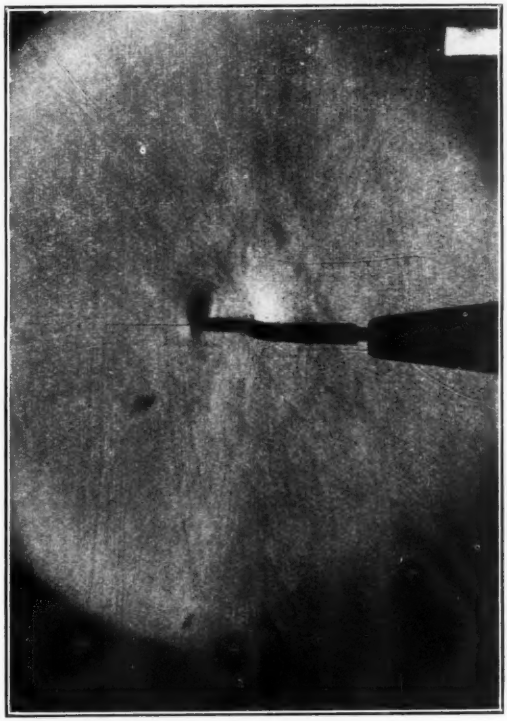


FIG. 19.

DISCUSSION BASED ON THE OPTICAL RESEARCHES.

The results of the optical researches, in conjunction with those obtained from the experiments, led us to search for a logical connection between the successive phenomena and to study their causes.

A probable explanation of the succession of phenomena, which we have deduced from our experiments, is the following:—

When, through expansion on the leading edge of the upper surface of the wing, the speed of sound has been reached or surpassed locally, the subsequent recompression takes places brusquely by means of a shock wave. As the region in which the speed of sound has been surpassed is initially small, the wave is of small dimensions.

The wave is not perpendicular to the profile; consequently the shock is oblique. It gives rise, therefore, to a deviation of the velocity from its original direction, upwards. This deviation tends to detach the airflow from the profile immediately after the shock; this detachment being visible optically.

At first the deviation is very small, because the velocity before the shock is very little greater than the speed of sound, and because the wave is not much inclined; hence the disturbance caused by the detachment is slight.

After the shock the speed again becomes subsonic, so that the consequent divergence of the streamlines on the back part of the upper surface generates a recompression (*Italian* ricompressione).

As the M.n. increases, the velocity ahead of the shock augments; so does the tilt of the wave and hence the detachment. The lift coefficient decreases, while the drag coefficient increases.

FIG. 20.

With still further increase in M.n., the shock becomes steadily more intense, because the speed ahead of it is higher; the wave goes on tilting, until it becomes so oblique that the speed behind the shock can reach and surpass the local speed of sound.

At this point the phenomenon changes abruptly: the divergence of the streamlines after the shock no longer causes recompression but expansion, since it is in the supersonic field; there is again an increase in speed, up to the point where the streamlines cease to diverge and recompression should begin; here there must necessarily be a second shock.

If the speed grows still higher, the increase in deviation of the velocity from its primary direction reduces the divergence of the streamlines; the expansion is less extended and recompression begins earlier. The second shock wave tends to approach the first, which, being tilted, at a certain point interferes with it.

Then begin the oscillations of the two shock waves, and corresponding oscillations of the resultant aerodynamic forces. The cause of this phenomenon escapes us altogether. The front wave tends to move backwards, and naturally displaces the second wave which is closely joined to it and which has a forward tendency.

As the speed grows, the oscillations of the two waves and their mutual interference also increase, until at a certain point they are damped out and come to an end, because the two waves have grown considerably and have taken up an inclination which eliminates their interference. The first wave is much farther back; the second upper wave has also moved backwards until it has passed off the trailing edge. A corresponding wave now appears on the lower surface, also originating from the wake.

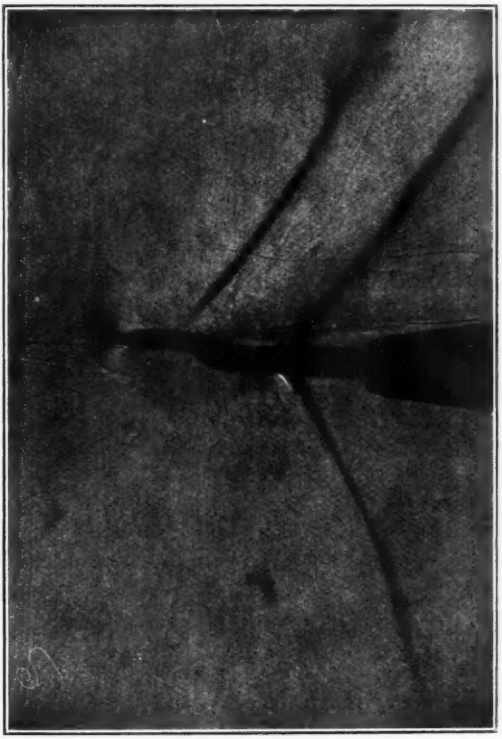


FIG. 21.

This arrangement of the waves is evidently favourable to low pressure on the upper surface, since in the first place the low pressure zone grows ahead of the first shock, and in the second place, there is a great expansion after the shock. In fact, as the first wave moves backwards beyond the point of maximum wing thickness, it causes a noticeable deviation of the velocity ahead of the shock from the direction of the undisturbed current; so that, although deflected by the shock, this divergence persists even afterwards and gives rise to a marked increase in speed.

The appearance of the lower shock wave leads us to suppose that a low pressure zone capable of accelerating the airflow must be created also on the lower surface near the trailing edge.

From the photographs, it seems that the phenomenon may be explained as follows:—

Behind the first upper wave there forms a turbulent wake with reduced speed but low pressure, since the airflow outside the wake has undergone a marked expansion.

Consequently, near the trailing edge pressure is less on the upper surface than on the lower.

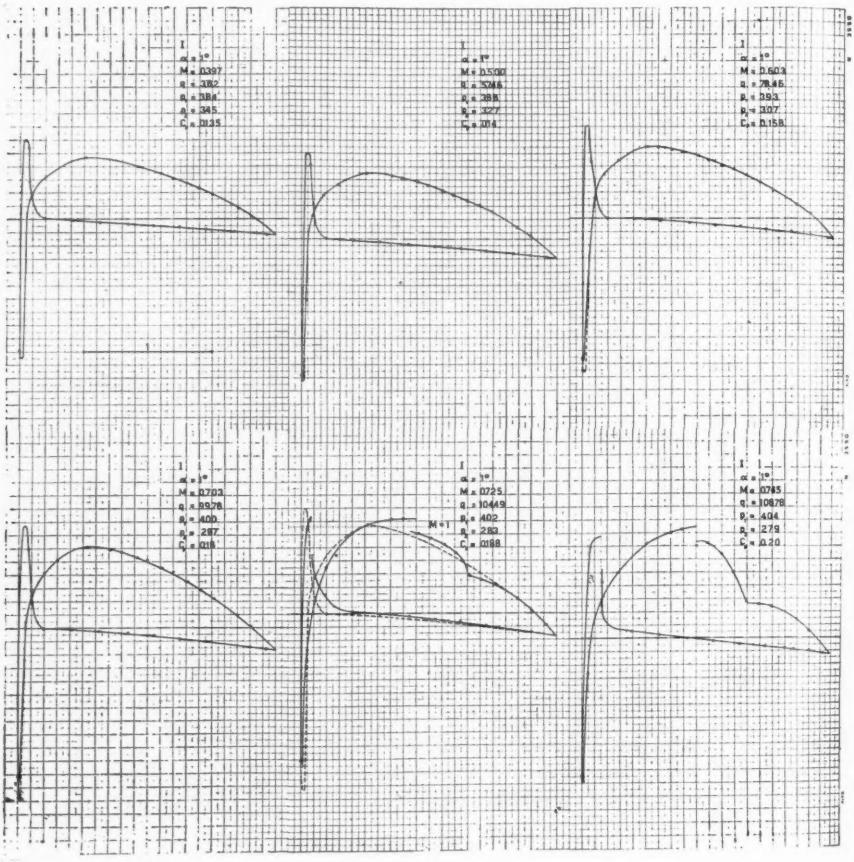


FIG. 22.

When the air coming from the lower surface meets the air from the upper, which is at a lower pressure, there must be a levelling of pressure; consequently the air from the lower surface expands, while the air from the upper surface contracts. In expanding, the airflow on the lower surface surpasses the speed of sound and is also deviated upwards. As a result, at a certain point it meets the upper current, which is travelling in a different direction. At this point the two currents must level their pressures and take the same direction, deviating from their original course. This levelling and deviation can only take place by means

of two shock waves, which must originate from the point where the two currents meet; this being just behind the trailing edge.

RESULTS OF THE PRESSURE READINGS.

In order to distinguish better the various aerodynamic phenomena and to check the various hypotheses formulated, we determined the pressure distribution along

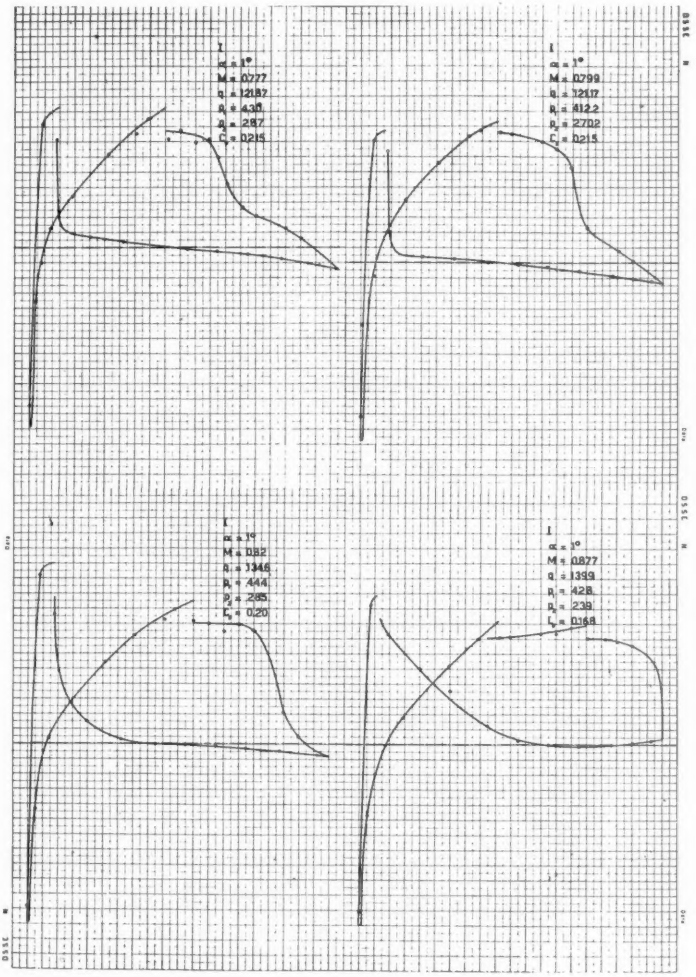


FIG. 23.

the upper and lower surfaces of the entire wing-span, at different speeds and angles of incidence. So as to determine, at least qualitatively, what effect the dimensions of the jet had upon the results, it was necessary to test the same wing in different jets. The experiments were therefore made first in the smaller jet and then in the one which had a cross-section of 50 × 40 cm.

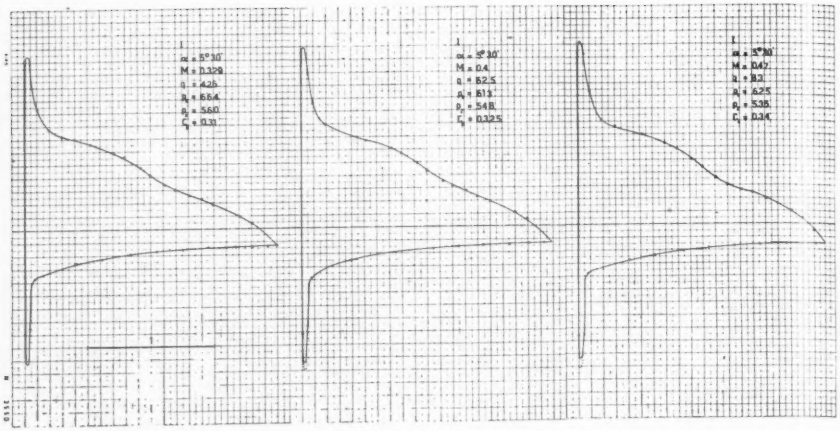


FIG. 24.

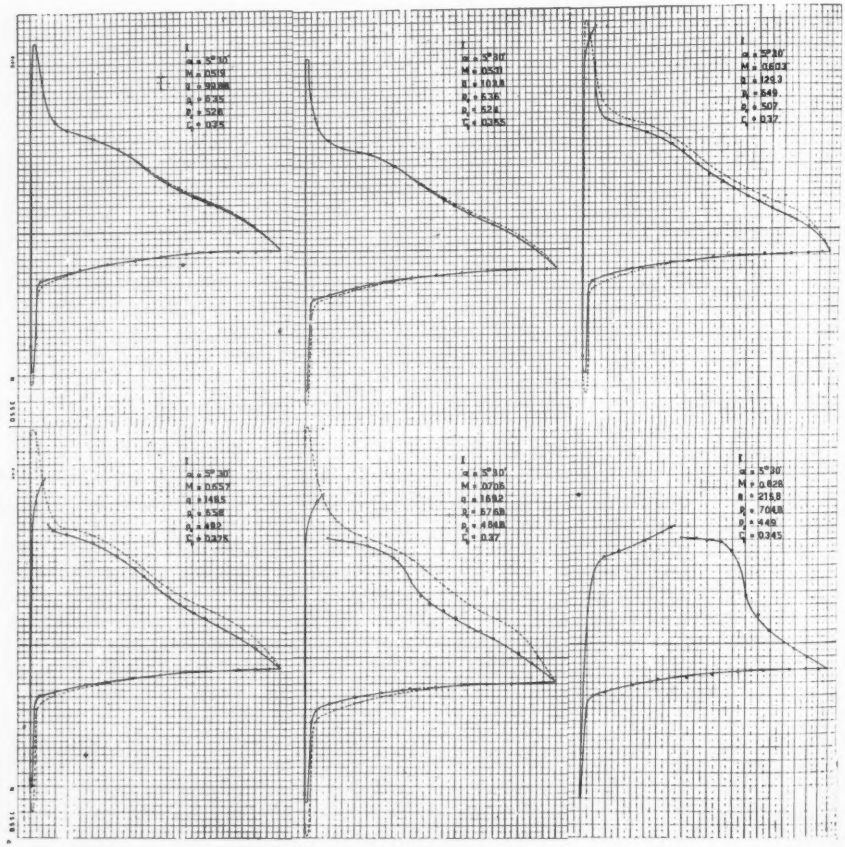


FIG. 25.

In the latter, we carried out two series of tests at various angles of incidence. In the first series, the current from the narrow section of the jet emerged into a test chamber 62 cm. high; in the second, the chamber was 74 cm. high. This was to give us an idea of what effect the dimensions of the layer of air which was in contact with the current on two sides would have on the results.

From these experiments the following conclusions were drawn: so long as the static pressure on the edges of the current remains constant in the two sections

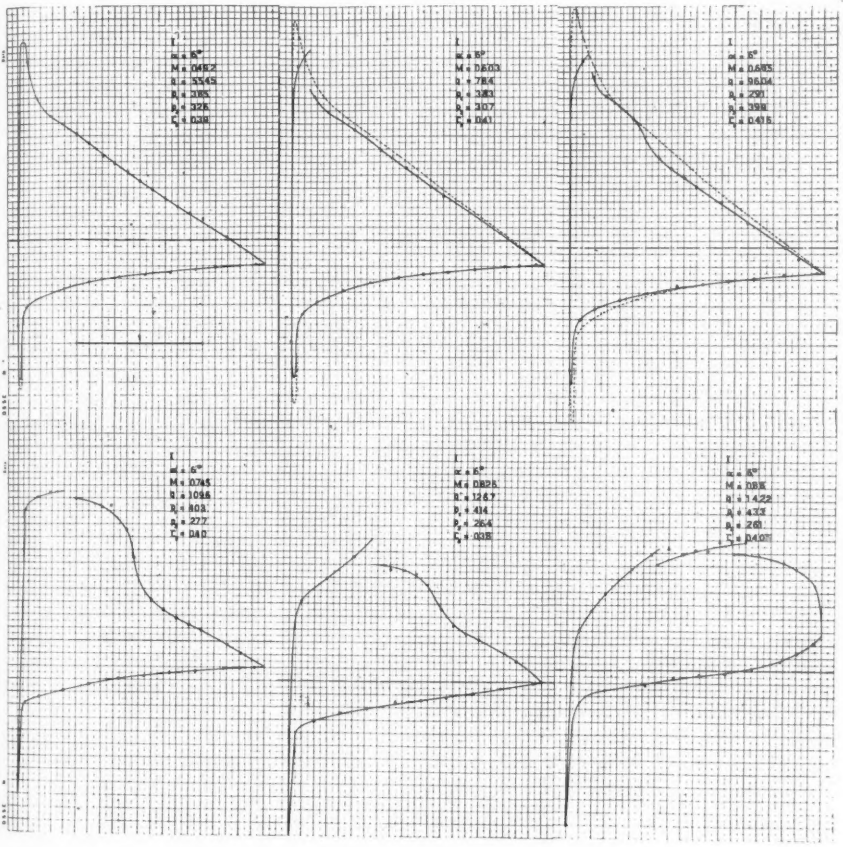


FIG. 26.

above and below the wing, the results are practically the same, whatever the dimensions of the jet. If, however, the aerodynamic phenomenon also affects the air surrounding the current, the results obtained are noticeably different between one jet and another.

Since with increase in the height of the jet the M.n., relative to the size of the model, which can be reached while still maintaining the requisite conditions, also increases, for high M.n. a jet of considerable height is necessary.

The difference in size of the chamber in which the current emerges, up to the value of M.n. reached, did not noticeably affect the results, but it did affect the

regularity of the current and the behaviour of the velocity along the axis of the jet.

We made a large number of experiments with the two jets, but for the sake of brevity I will only mention a few of them; to be precise, those made at angles of incidence ranging from 1° to 6° in the 50 × 40 cm. jet. In justification of what I have stated above, regarding the influence of the size of the jet upon results, I will also quote two series of experiments at angles of incidence of approximately 6°, one made with the 28 × 40 cm. jet and the other with the 50 × 40 cm. jet, but with a test chamber 72 cm. high.

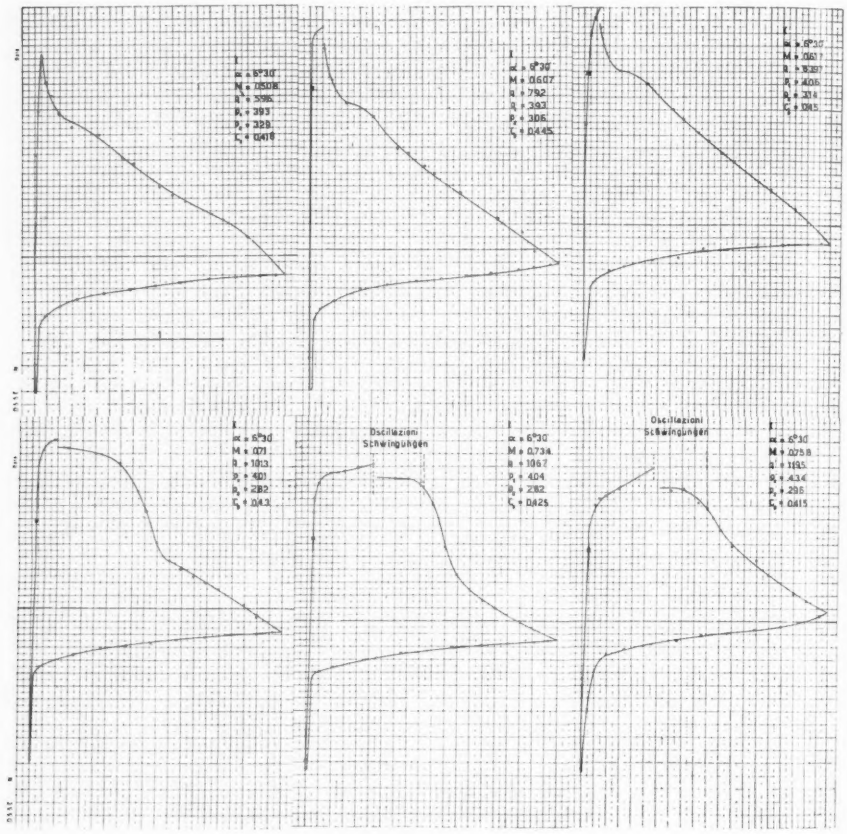


FIG. 27.

While conducting these experiments we kept checking the pressure at the edges of the current, and we suspended them immediately this pressure showed signs of alteration.

All the diagrams were obtained by measuring the difference of pressure between the pressure in the test chamber and that which existed at different points of the wing, and dividing those differences by the value of the pressure q calculated according to the formula:

$$q = \tfrac{1}{2}\rho v^2$$

Consequently the ordinates of the diagrams represent these ratios, and not dimensional magnitudes; each graph shows, besides the angle of incidence and the M.n., the values of q, of p_1 (pressure upwind of the jet), of p_2 (pressure in the test chamber) and of C_L, which last was obtained approximately, by integrating the area of the diagram. The pressures are expressed in millimetres of mercury.

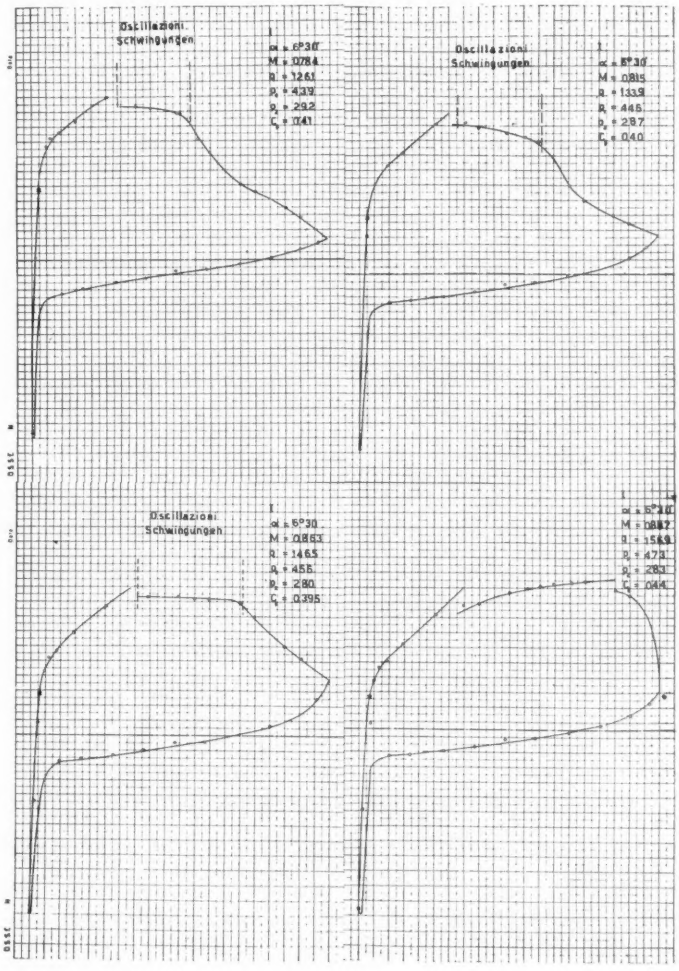


FIG. 28.

The series of diagrams for angles of incidence of 1°, 5° 30′, 6°, 6° 30′, are given in Figs. 22, 23, 24, 25, 26, 27 and 28.

The diagrams for an angle of incidence of 5° 30′ were obtained with the 28 × 50 cm. jet; consequently, as we had to limit ourselves to relatively low M.n., we dealt more in detail with the values obtainable than in the other cases.

The diagrams for an angle of incidence of 6° 30′ were obtained with the 50 × 40 cm. jet and the 74 cm. test chamber.

The following conclusions can be drawn from these diagrams, and from the others which we drew up:—

(1) At low speeds, until the shock wave appears, the behaviour of the pressures is in agreement with the Prandtl-Glauert theory. In fact, starting from the diagram obtained with the lowest M.n. and working out graphs for the succeeding M.n.'s on the basis of this theory (as indicated by the dotted lines), we see that these differ very little from those obtained by actual experiment. In general, these differences occur only in the high-pressure zone, where the theoretical diagram gives higher values than were found in practice.

(2) As soon as, through the low pressure, the speed of sound is surpassed, the subsequent recompression takes place by means of a shock wave. This shock noticeably affects the behaviour of the pressure. In fact, before the shock the expansion becomes less accentuated, and at high M.n. is very gradual. After the shock the low pressure, having slowly decreased for a while, drops rapidly and brusquely; so much so, that it seems as though a deep turbulent wake were formed at this point, perhaps due to the deviation of the airflow by the shock.

(3) As the speed goes on increasing, the shock tends to move backwards. The low pressure in front shrinks still more. After the shock the low pressure is less and continues to behave as we have just described it, although the recompression after a while becomes less abrupt. A slight low pressure begins to form on the under surface near the leading edge, due to the fact that the airflow coming from the upper surface has an upward tendency and creates an acceleration in the lower current. The diminution of the low pressure on the leading edge and the shrinkage at this point in the diagram of the low-pressure zone, seem to us logical and easily explained. In fact, one can reason more or less as follows: Where a low pressure zone forms and there is a positive gradient of low pressure, there must be an increase in speed. The latter, for normal speeds, must be due to the convergence of the streamlines at this point. At the end of the convergence of the streamlines the low pressure is most accentuated, and here the speed is greatest; then the recompression begins. In the field of sound, this convergence of the streamlines becomes less effective, the higher the M.n. In fact, at the point of convergence the velocity may increase but cannot surpass the speed of sound; now, if the M.n. is low, the augmentation in speed and consequently in low pressure which occurs in this zone is considerable; if the M.n. is high, the speed of sound is almost reached, while the gradient of velocity and of low pressure remains slight. Naturally, at the point of divergence the speed of sound may be surpassed; hence there is a subsequent expansion, which only stops when the shock wave forms.

To verify this explanation, we checked up the point in the various diagrams where the speed of sound was reached. This comparison, made in the series of experiments at an angle of incidence of 6° 30′ (assuming an adiabatic expansion), showed that, at a very near approximation, the speed of sound is reached at the point where, for low speeds, the maximum low pressure occurs. A small star on the diagrams indicates the point at which the speed of sound is reached. We selected the series 6° 30′ because this is the one which has the greatest number of points marked in this zone.

(4) With still further increase in speed, supersonic speed occurs after the shock. The phenomenon changes, because after the first shock there is a subsequent expansion, leading to a marked increase in speed. We are once again in the supersonic field, and the recompression must take place by means of a second shock. After this there is again a marked low pressure, because the expansion on the lower surface near the trailing edge is accentuated.

Since the low pressure on the upper surface is intensified, the lift coefficient of the wing increases. The behaviour of the C_L diagram as a function of M.n. again

has an upward tendency, and in the values preceding the second shock wave it reaches a minimum.

(5) As the M.n. increases, the low pressure near the leading edge diminishes, whilst the low pressure on the under surface increases proportionately; at high M.n., when the second wave appears, it also grows in the vicinity of the trailing edge. Consequently, the centre of the pressure of the profile distinctly moves backwards, and the pitching moment of the wing relative to the leading edge increases with the increase in speed.

(6) The values of C_L, obtained approximately by integrating the areas of the pressure diagrams, indicated in the graphs as a function of M.n., are fairly well aligned, and give curves similar to those which were drawn from the measurements of forces. (Fig. 29)

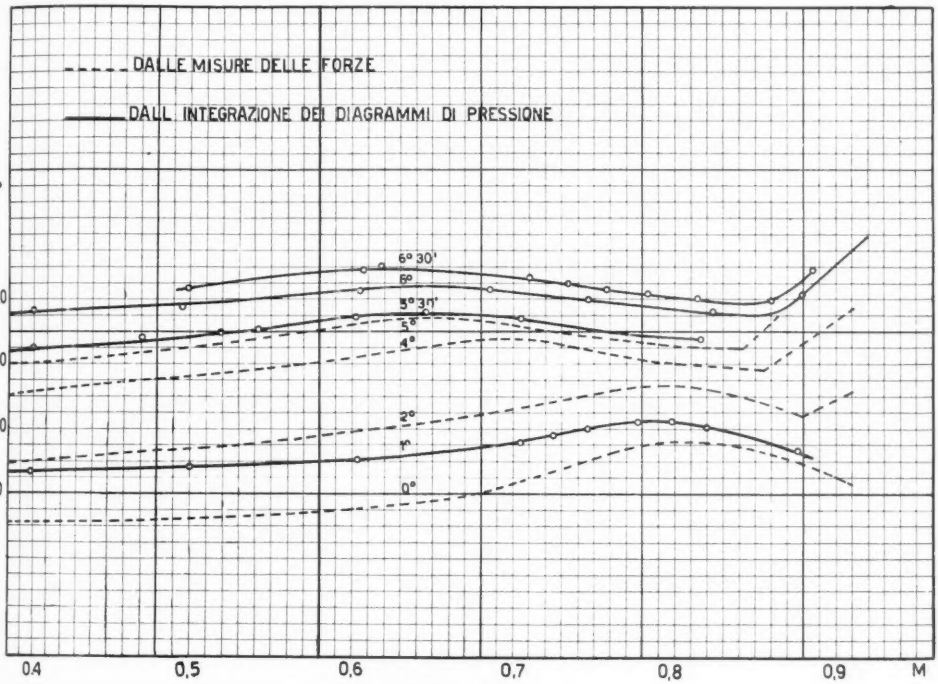


FIG. 29.

This agreement in the results appears to us very interesting, as it helps to resolve many of the doubts which might arise, as to whether the results obtained were dependent upon the method used in making the experiments.

In fact, passing from the measurements of forces to those of pressures, the conditions of our experiments were completely altered—from the ratio: dimensions of the jet: dimensions of the model to the Reynolds number—without any fundamental discrepancy appearing in the results.

This fact leads us to hope that our method of experiment may give useful results that will be applicable in practice, and encourages us to persevere in the same direction.

Of course, there still remains a great deal to be done, so far as the method is concerned, to give greater precision in the observations. We hope, however, that

this first series of results may soon be supplemented by others, more complete and more perfect, which will enable us to grasp the connection which exists between the results obtained and the characteristics of the profile. Thereby we hope to furnish those elements which have become essential to modern aeronautics, and so to contribute to that progress which is the goal of all experimenters.

These researches were carried out at Guidonia, at the Head Office for Study and Experiment of the Italian Air Ministry, under the direction of General Fernando Bertozzi-Olmeda. The experiments were made in the supersonic wind-tunnel of the Aerodynamic Section, under the guidance of Captain Antonio Eula, Chief of the Section. Professor Luigi Crocco assisted us in interpreting the phenomena.

REVIEW.

THE OIL ENGINE MANUAL.
D. S. D. Williams, A.M.I.A.E., and J. Millar Smith, B.Sc. Temple Press, Ltd., London. 5/- net.

The heavy oil engine has made remarkable progress in the past few years. This work is an account of the development and a description of the operation and types of oil engines in use.

The need for a cheaper and safer fuel than petrol has become increasingly urgent with the coming of the aeroplane. The authors very rightly give the credit to H. Akroyd Stuart for the first main development in the oil engine. Akroyd Stuart's work, indeed, was of primary importance and his pioneer developments are recognised by the Royal Aeronautical Society and other bodies which have an Akroyd Stuart Memorial Prize among their awards. The intensive development work which took place in Germany, following the theoretical and practical work of Dr. Diesel, has overshadowed the work of Stuart. Diesel was a brilliant engineer who foreshadowed the value of the oil engine and its greater efficiency over the petrol engine, from purely theoretical considerations.

Chapter II of this book is devoted to the working principles, definitions and types. It is illustrated with extremely clear diagrams which are, indeed, an excellent feature of the book throughout. Chapter III explains injection, ignition and combustion, and covers combustion chamber types and fuel ejection equipment. Various types of starters are described in the following chapter. The different types of industrial oil engine in use are very fully described in succeeding chapters, and on pages 122-129, 219-224 are tables of horse-powers, weights, speeds, etc., of all the British horizontal and vertical oil engines. To the aircraft engineer it is interesting to note engines of 240 rated b.h.p. weighing 55,000 lbs.!

The real importance of the oil engine is its comparatively recent development for road transport and its possible further development for aircraft work. In a brief ten years the development on a basis of horse-power for road transport alone in Great Britain has overtaken that of stationary and marine Diesel units.

Chapter XVI is the only chapter devoted to aircraft oil engines. It is doubtful if the leading exponents of the petrol engine will agree with all the comparisons made in this chapter to the advantage of the Diesel.

The book contains useful and interesting tables of operating costs for transport vehicles using Diesel engines.

For all those who are interested in the development of the oil engine this manual should prove of use and value, as a record of progress and current practice.

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS.

MONTHLY NOTICES.

NOVEMBER, 1939.

President's Letter.

The President's personal letter, already circulated to all members, will be published in the December issue of the Journal, together with a list of donations to the Society.

Emergency Address.

During the period of the war correspondence may be addressed either to headquarters or to the Society's country address, Brook House, Old School Lane, Brockham. (Telephone Betchworth 189.)

Journal.

Many members have inquired what is going to happen to the Journal and will it be published as regularly as in the past?

The two chief difficulties of keeping the Journal going in wartime are (1) the supply of paper, (2) the supply of articles.

The Editor has made arrangements for six months' supply of paper on the assumption that the Journal will continue to be published monthly in its present size and number of pages. Immediately on the outbreak of war the Editor approached a number of personal friends in America and the response has been overwhelmingly generous. Full permission has been given to reprint any articles from papers edited or controlled by those approached, papers which will not be easily obtainable in this country at present, and many of the leading designers and technicians in the United States have offered to help to obtain original or unpublished papers for the Journal.

In particular the Society owes a deep debt of gratitude to Mr. Lester Gardner, Honorary Fellow and Executive Vice-President of the Institute of the Aeronautical Sciences, who has personally approached many of the leading authorities in the United States for papers; to the Committee of the N.A.C.A. and to Dr. George Lewis, Director of Aeronautical Research, for permission to publish in full or in part N.A.C.A. Reports or Technical Notes; to Professor J. C. Hunsaker, Honorary Fellow, Editor of the Journal of the Institute, who has given permission to make use of any papers the Institute publishes; to Mr. Arthur Nutt and Mr. Norman G. Shidle, Executive Editor of the Journal of the Society of Automotive Engineers, who have given similar permission for papers in the S.A.E. Journal, and who are also arranging for unpublished papers to be considered for the Society's Journal; and to Mr. Paul Johnson, who has given permission for any papers to be published in full or in abstract from "Aviation."

The publication of the Abstracts from the Scientific and Technical Press is resumed this month and will be continued.

In future issues will appear translations of important papers from the foreign technical press, as they may be available.

Every effort is being made by the Editor to publish more information now than in peace time and to make the Society a central source of technical information as far as possible. Original papers by members of the Society will be welcomed.

Central Register.

It has been decided to extend the Central Register to include Graduates, Students who hold a degree or its equivalent, and Associates. Central Register classification cards have accordingly been sent to these members.

The Central Register of the Ministry of Labour contains particulars of scientific, technical, professional and higher administrative personnel of the country who have volunteered for suitable work in war time either in the Public Services or with employers engaged on work of national importance.

The object of the Central Register is to ensure that in war time work of national importance, for which specialist qualifications are necessary, is performed by those persons best qualified to undertake it. There is no obligation on employers to notify their vacancies to, or to accept persons from, the Central Register, but it is hoped that many employers whose firms are engaged on work of national importance will find the Central Register of great assistance. The service provided is free. The Secretary is a member of the Central Register Committee dealing with aeronautical engineers and will answer any questions which any member may raise.

History of the Society.

The Secretary is collecting material for a detailed history of the Society since its foundation on January 12th, 1866. He will appreciate anything of interest bearing on the Society's history and the loan of any letters or documents which will be copied and returned. He would particularly welcome any personal reminiscences of meetings of the Society and its unrecorded activities during the period 1904—1914 and any letters, circulars, newspaper references, or papers relating to the Society before 1904.

Acknowledgments.

The Council acknowledge with grateful thanks the gift of Journals from Mr. Griffith Brewer, Honorary Fellow and Vice-President.

Examinations.

The Society's Examinations will be held on December 20th, 21st and 22nd, at the City and Guilds (Engineering) College, South Kensington, S.W.7, by kind permission of the College authorities. Full particulars will be sent to those candidates who have entered.

Library.

Members are reminded that books will be sent through the post to those who cannot get to the Library at 4, Hamilton Place. The books must be registered both ways, the borrower paying postage.

Election of Fellows.

The following were recently elected Fellows of the Society:—

Francis Thomson Hearle.
Herbert Geoffrey Morcom.

Corrections.

In the paper on Experimental Research in Guidonia Supersonic Wind Tunnel, Figs. 13 and 16 should be reversed, Fig. 16 at the bottom of page 817 should read Fig. 15 and Figs. 17, 18 and 19 should be reversed.

Additions to Library.

National Advisory Committee for Aeronautics: Reports:—

No. 650. The Aerodynamic Characteristics of Six Full-Scale Propellers having different Aerofoil Sections. By D. Biermann and E. P. Hartman.

No. 655. The Knocking Characteristics of Fuels in Relation to Maximum Permissible Performance of Aircraft Engines. By A. M. Rothrock and A. E. Biermann.

No. 656. The Column Strength of Two Extruded Aluminium Alloy H-Sections. By W. R. Osgood and Marshall Holt.

No. 657. The Influence of Directed Air Flow on Combustion in a Spark-Ignition Engine. By A. M. Rothrock and R. C. Spencer.

No. 659. Effect of Service Stresses on Impact Resistance, X-Ray Diffraction Patterns and Microstructure of 25 S Aluminium Alloy. By J. A. Kies and G. W. Quick.

No. 660. Experimental Investigation of the Momentum Method for Determining Profile Drag. By Harry J. Goett.

No. 663. The Effect of Continuous Weathering on Light Metal Alloys Used in Aircraft. By Willard Mutchler.

No. 666. Aircraft Rate-of-Climb Indicators. By Daniel P. Johnson.

National Advisory Committee for Aeronautics: Technical Notes:—

No. 705. Wind Tunnel Investigation of Ground Effect on Wings with Flaps. By Isidore G. Recant.

No. 706. An Experimental Investigation of the Normal Acceleration of an Aeroplane Model in a Gust. By Philip Donely.

No. 708. A Simplified Method for the Calculation of Airfoil Pressure Distribution. By H. Julian Allen.

No. 709. A Semi-Graphical Method for Analysing Strains Measured on Three or Four Gage Lines Intersecting at 45°. By H. N. Hill.

No. 710. A Comparison of Ignition Characteristics of Diesel Fuels as Determined. By Robert F. Selden.

No. 711. An Approximate Spin Design Criterion for Monoplanes. By O. Seidman and C. J. Donlan.

No. 712. A Preliminary Study of the Prevention of Ice on Aircraft by the Use of Engine Exhaust Heat. By Lewis A. Rodert.

No. 713. A Comparison of Several Tapered Wings Designed to Avoid Tip Stalling. By Raymond F. Anderson.

No. 714. Flight Tests of Retractable Ailerons on a Highly Tapered Wing. By J. W. Wetmore.

No. 715. Wind Tunnel Investigation of an N.A.C.A. 23,012 Airfoil with Two Arrangements of a Wide-Chord Slotted Flap. By Thomas A. Harris.

Atti di Guidonia:—

Nos. 8-9. Nuovi Sviluppi sul Meccanismo a Biella Madre e Bielletta e Questioni Dinamiche nei Motori Stellari. (New Developments in Master and Articulated Connecting Rod Assembly: Dynamic Problems of Radial Engines.) By Prof. Luigi Crocco.

No. 10. Introduzione di un nuovo e generale " Principio di Equivalenza " per lo Studio delle Strutture Elastiche. (Introduction of a New and General " Principle of Equivalence " for the Study of Elastic Structures.) By Dr. Luigi Broglio.

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Quenching Tests in Various Media. (2nd Report of Sub-Committee A, Part 7.) By G. Stanfield.

A Study of a Nickel-Chromium-Molybdenum-Vanadium Steel Ingot. By Dr. W. H. Hatfield.

The Vacuum Fusion Method for the Determination of Oxygen in Steel. A Carbon Spiral Vacuum-Fusion Furnace as in Use at the Brown-Firth Research Laboratories. (2nd Report of the Oxygen Sub-Committee, Part 2D.) By W. C. Newell.

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J. Laurence Pritchard, *Secretary and Editor.*

The 645th Lecture read before the Royal Aeronautical Society since its foundation on January 12th, 1866.

PROCEEDINGS.

A Meeting of the Royal Aeronautical Society was held on Thursday, March 16th, 1939, in the Lecture Hall of the Institution of Mechanical Engineers, by permission of the Council of the Institution, when a lecture on "A Review of the Relative Merits of Petrol Injection and Carburettors for Aero Engines" was read by Messrs. J. E. Ellor, F.R.Ae.S., and F. M. Owner, M.Sc., F.R.Ae.S.

In the chair, Mr A. H. R. Fedden, President of the Society.

The CHAIRMAN: Before they got to the business of the evening he had one announcement to make. Last night, at the Council Meeting of the Society, it was decided unanimously by the members of the Council to propose the election of Major Lester Gardner as an Honorary Fellow of the Royal Aeronautical Society. As was known, Major Lester Gardner was the Secretary of the Institution of Aeronautical Sciences in New York, and had played a considerable part in aeronautics in that country. He had based the Institution on the Royal Aeronautical Society and had always kept in the closest touch with them. There were two other American Honorary Fellows, Mr. Orville Wright and Mr. Hunsaker. It was the rule of the Society that at the next general meeting it should be decided whether the Council's decision in regard to that high honour should be confirmed, and he would ask all members of the Society present that evening to vote as to whether they were in agreement with the decision.

A show of hands was taken, and the Council's decision was confirmed.

The CHAIRMAN, continuing, said that a message would be cabled to Major Gardner informing him of the considerable honour that had been conferred upon him. The Chairman added that they were to have the pleasure of Major Gardner's presence at the Wilbur Wright lecture by Dr. Lewis, of the N.A.C.A.

That evening the Society were having somewhat of an innovation in the form of a joint paper by two Fellows of the Society on an important and controversial subject upon which there was a wide divergence of opinion in the aero engine world, and he hoped that they would have an interesting meeting. Both the authors had obtained distinction in British aero engine endeavour and both had had a wide experience of the particular aspect of the subject to be dealt with that evening. Mr. J. E. Ellor was for twelve years at the Royal Aircraft Establishment on research work on aero engines before he joined the Rolls Royce Company as development and research engineer in 1927. Mr. F. M. Owner had been with the Bristol Company since he took his engineering degree at Manchester in 1922, and had been engaged upon a varied number of design problems. He was at present assistant chief designer of the Bristol Company on the engine side. Mr. Owner would now read the paper entitled "A Review of the Relative Merits of Petrol Injection and Carburettors for Aero Engines."

A REVIEW OF THE RELATIVE MERITS OF PETROL INJECTION AND CARBURETTORS FOR AERO ENGINES.

By J. E. Ellor, F.R.Ae.S., and F. M. Owner, M.Sc., F.R.Ae.S.

Introduction.

The subject of the carburettor as opposed to fuel injection is one which has created much controversy in aero engine design and development. Current opinions both in this country and abroad are many and varied and it would be presumptuous to forecast which will eventually predominate. The object of this paper is to present an unbiased review in the hope of provoking a useful interchange of opinions and experiences.

It might be argued that claims for one system can be countered by claims for the other and to be impartial it is necessary, therefore, to be familiar with as many facts and as much published information as possible. Owing to the meagre amount of information available on fuel injection, the paper is not as complete a review as the authors would wish, but it is hoped that sufficient material has been presented to be helpful to those who are interested in the subject.

It must be borne in mind, however, that the standard of progressive development must be judged on the benefits received by the user, and to justify any major change in design or operational technique, the advantages must be sufficiently great to make the introduction worth while.

In assessing the relative merits due consideration should be given to the following items:—

(1) Improvement in performance.
(2) Simplification of operation and servicing.
(3) Facilities and cheapness of production.
(4) Reliability.

Past experience supplies ample evidence of the fact that we engineers are always being presented with more difficult problems to solve and whilst this is a true progressive spirit, it is undesirable to waste time and energy in merely achieving the same results in a different manner unless material benefits are obtained.

A well known American aero engineer, when asked some years ago for his views on the benefits of fuel injection compared with the carburettor, stated that if the aero engine as developed, incorporated fuel injection instead of the carburettor, there would have been a section just as anxious to fit the carburettor as they are apparently anxious to fit fuel injection at the present moment.

It is hoped, therefore, to clear the air a little by carefully reviewing in a broad manner the existing carburettor systems and the information available on petrol injection systems.

Definitions.

Three distinct principles are involved in the possible methods of introducing the fuel into the engine cylinders:—

(1) Continuous induced flow, as in the case of the carburettor.
(2) Continuous injection.
(3) Timed injection.

In the first and second case, the fuel should enter the induction system at a point sufficiently far removed from the inlet valve to enable the pulsations in the air flow to be damped out and to ensure good distribution. A very suitable point for continuous injection is at the eye of the supercharger impeller whilst the carburettor may be placed either at the inlet or outlet of the supercharger.

It is usual to exclude carburettors from the definition of continuous injection devices. This convention is convenient and will be adopted. It should, however, be understood that a carburettor is in reality a method of injecting fuel continuously. Usually fuel is sucked by the air flowing through the carburettor, whilst it is mechanically pumped when fuel injection is employed. A fundamental difference between the two methods does, however, exist and it materially affects the operational control in obtaining the desired fuel/air ratio. A carburettor will be defined, therefore, as a device permitting a continuous induced flow of fuel at a venturi by a pressure difference in this part of the induction system, the rate of flow being governed by a variable jet area and/or a variation of the pressure difference. Good atomisation of the fuel is also an important function of the carburettor.

In the case of timed injection, the correct quantity of fuel for the particular condition of cylinder charge is introduced either directly into the cylinder or into the induction pipe close to the inlet valve at a suitable point of the cycle. The injection is carried out at a fuel pressure sufficiently in excess of the pressure existing at the point of injection to promote satisfactory atomisation. The magnitude of the pressure is also a function of the injection period. Timed injection may, therefore, be defined as the introduction of fuel intermittently into or close to each cylinder as determined by the order of firing.

It is not the intention of the authors to review the possibilities of " Dieseling " with direct petrol injection nor to discuss the involved problems centring around the beneficial effects of stratified charge. These possibilities still remain in the research stages. Consideration is therefore given only to the merits of application to engines of the type now being used with carburettors.

The authors would also like to make it quite clear that for the two-cycle aero petrol engine there is no alternative to direct fuel injection into the cylinders.

Historical Review.

The authors do not know who first thought of carburettors and petrol injection. They can, however, say that both are older than the aviation industry.

The engine used by the Wright brothers in 1903 on their first flight had a wick type surface carburettor. Three years later the Wrights were making flights of several miles, using an improved engine with continuous injection. This early example was, naturally, somewhat crude and consisted merely of a small pump supplying fuel to a jet placed in a mixing chamber at the end of the induction pipe. Only two engine controls were provided—ignition timing and exhaust valve lifters.

In 1908 the French 50 b.h.p. " Antoinette " engine made its appearance, using timed injection. This eight-cylinder vee engine had automatic suction operated inlet valves above each of which was mounted a small injector, to which was connected a variable stroke piston type fuel pump, driven from the crankshaft. As each inlet valve opened fuel was injected in the induction pipe and mixed with the in-going air.

For a number of years interest in petrol injection was dormant because carburettors were able to meet the requirements of the day and they were a much simpler proposition mechanically.

Immediately after the Great War the subject was taken up by a number of French firms, but the first comprehensive programme of research was that commenced in 1925 by the U.S. Army Air Corps (1) (2). Tests were made on the continuous injection of fuel in the supercharger impeller eye, but later timed injection in the induction pipe was tried on a number of engines. A swash plate pump was specially designed for petrol injection by Mr. M. G. Chandler and built by the Marvel Carburettor Company (3) (4).

The results obtained from these tests seem to have been very satisfactory and a considerable amount of flying was done. It was even stated (1) that the Air Corps planned to acquire, after July, 1935, only engines fitted with fuel injection.

The reason why this prophecy was not fulfilled has never been stated publicly, but at that time the most difficult part of the system had not been tackled, namely, the controlling of fuel supply in flight.

Results of tests on a single cylinder unit at the Massachusetts Institute of Technology were published in 1931 (5), and they also claimed that petrol injection was superior to the carburettor. Experiments were made on the injection of fuel into the cylinder. Later (6), methods of producing turbulence were investigated and the subject of stratification and the possibilities of burning very weak mixtures by concentrating the combustible mixture around the sparking plugs began to be widely discussed. Hopes were awakened that some outstanding developments were about to be perfected because of the announcement of the new hydrogenated safety fuels (7) (8). These fuels were claimed to have octane values up to 95 without ethyl dope, and a flash point of about 50°C. (Cleveland open-cup method). They were considered, therefore, much safer than petrol having a flash point of about −26°C. Unfortunately, owing to their poor volatility they could not be carburetted. Tests by the M.I.T. and the N.A.C.A. (9) (10) showed, however, that the fuels could be used satisfactorily when injected into a cylinder and the suggestion was made that they would be suitable for two-stroke operation.

A number of improvements were then made to carburettors and this seems to have been the reason why fuel injection has at least temporarily flagged in America. Bendix Stromberg do, however, hint that they are interested in the continuous injection of fuel into the impeller eye (11) and the Continental Company appear to retain interest in the Marvel injection system (12).

Returning to this side of the Atlantic one hears rumours everywhere, but actual results are shrouded in secrecy.

Mr. H. R. Ricardo is, of course, busy experimenting and he reports (13) that the results obtainable with petrol injection depend entirely on the degree and nature of the turbulence. He announces that he has obtained some very good results with stratified charges in sleeve valve engines and he has found it possible to operate over an extremely wide range of mixture strengths.

After some 500 hours of single cylinder tests the Bristol Company built for the Air Ministry in 1932 a petrol injection engine which they named the " Draco," Fig. 1. It was essentially a medium supercharged " Pegasus " radial engine modified for petrol injection. Two Bosch fuel pumps were used and fuel was injected in the inlet elbow of each cylinder and against the airflow. The engine was tested on the bench by Bristol and the R.A.E., and in flight for many hours by the Westland Aircraft, Ltd. Excellent reports were received, especially from the pilots, their comments being briefly as follows:—

(1) The starting was very good, and more certain than with the carburettor.

(2) Slow running was excellent, and there was no tendency to deposit or get rich, an important point with modern engines. The engine would tick over for half an hour without hesitating, or wetting the plugs.

(3) Acceleration was absolutely certain, and there was never any backfiring or sluggishness.

(4) The engine would shut down more positively than with a carburettor to the same slow running speed.

(5) Icing had been entirely eliminated even though special flight tests were made in the worst possible conditions.

Tests were continued until 1935 when the conclusion was reached that further research on the " Draco " was not at that time warranted. The reasons for this decision were:—

(1) No measurable reduction in fuel consumption had been obtained by petrol injection.

(2) The rated altitude of the " Draco " was slightly less than for the standard " Pegasus." This was due to the reduced density of the air in the supercharger owing to the absence of petrol.

(3) The distribution of radial engines is excellent and cannot be improved by petrol injection.

This historical review of petrol injection for aero engines would not be complete without some reference to the Hesselman engine (14), (15), (16), even though it has not yet been used for aviation. It is a low compression engine capable of running on a very wide range of fuels, thanks to its injection system, its turbulent combustion chamber, and its spark ignition. The first production engine was built in 1932 and since then a very wide range of models have been developed, mostly for heavy vehicles.

Another engine of the same type is the Ares (17), (18), (19). Turbulence is produced by a vaned ring in the combustion chamber.

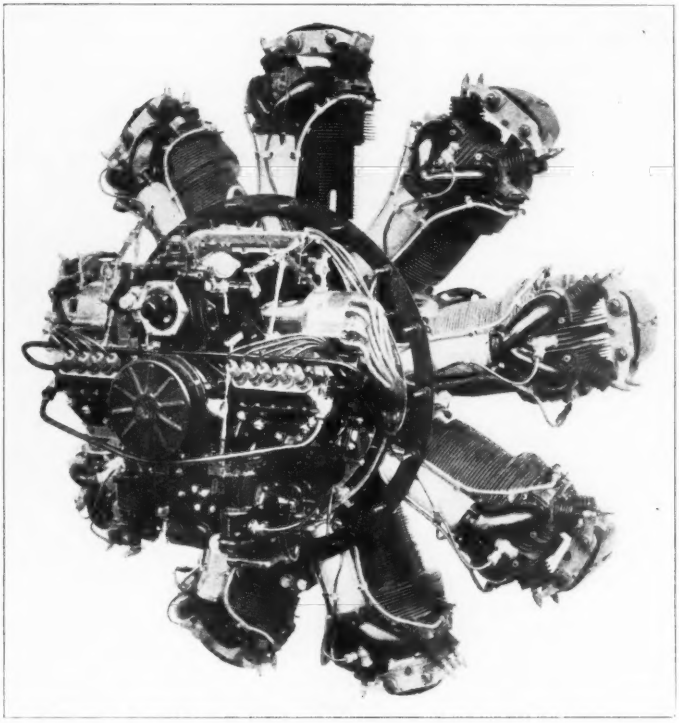


FIG. 1.

From 1936 onwards reports on petrol injection have been current from many quarters. The main aim of the experimenters appears to have been to improve the distribution of their engine, but the desire to abolish the float chamber for military reasons has probably also been a consideration.

Published reports state that by fitting timed injection to the nine-cylinder radial Lorraine " Algol " engine a 5 per cent. increase in power and a 10 per cent.

* See Section on " Continuous Injection " in this paper.

decrease in fuel consumption are obtained. The same firm has also adapted its 12-cylinder vee " Sterna " engine to petrol injection (20).

In Italy the " Caproni Fuscaldo " electro-magnetic fuel injector is announced (21). The claim is made that this device has enabled 27 per cent. reduction in fuel consumption to be made on a " Piaggio " radial engine. We venture to suggest that these normal characteristics were not up to standard.

The country most interested in fuel injection is undoubtedly Germany, where it is reported that engines of a number of makes are being tested with the system. Published data is scarce, but it would appear that the take-off power of the Junkers Jumo 211 has been raised 10 per cent. due to petrol injection (22).

From the abridged review it will be understood that much evidence of the considerable interest in petrol injection is available, but not many facts or results of systematic tests can be quoted.

To review the history of the carburettor would occupy many more pages than are at our disposal, but by evolutionary development the modern types embody all the necessary features for the efficient functioning of an aero engine and fulfil the varied fuel metering requirements for the different conditions of running.

To meet these demands and to reduce the number of pilot's controls to a minimum, extra parts have had to be added to the carburettor though the original conception of the simple venturi carburettor is still retained.

Much thought has been given at home and abroad to the replacement of what is generally accepted to be an unmechanical device, namely, the float chamber system, and a satisfactory control of the fuel supply to the carburettor is now obtained by valves operated by diaphragms.

Automatic control of the carburettor for altitude conditions is now fairly general, so that the pilot need only have a single control operating the throttle for normal flight conditions, and an additional lever for ultra weak cruising when these conditions are required.

The Problem of Carburation.

(1) Function of Modern Carburettors.

Two main functions must be performed by a carburation device, be it a carburettor or an injector :—

(1) The air flow must be measured,
(2) The fuel must be metered,

whilst the correct relationship under varying conditions of operation must be achieved.

The first named function can be accomplished by a choke, either fixed or variable, or by an indirect method, such as the measurement of the product of the density in the induction pipe by the engine r.p.m., with suitable correction applied depending upon engine characteristics (Fig. 2).

The second function is the more awkward because the fuel should be metered according to a very complicated law and it is necessary to provide :—

(1) A rich mixture for slow running.
(2) A weak mixture for economical cruising.
(3) A normal rich mixture for high power cruising.
(4) An extra rich mixture for take-off.
(5) A temporary enrichment when the engine is accelerated.

To perform each of these functions separate devices are generally required, each of which may be capable of independent calibration and adjustment.

Each function should be performed correctly when changes in the following variables occur :—

(1) Barometric pressure.
(2) Atmospheric temperature and changes in charge temperature consequent on variation of supercharger compression ratio.

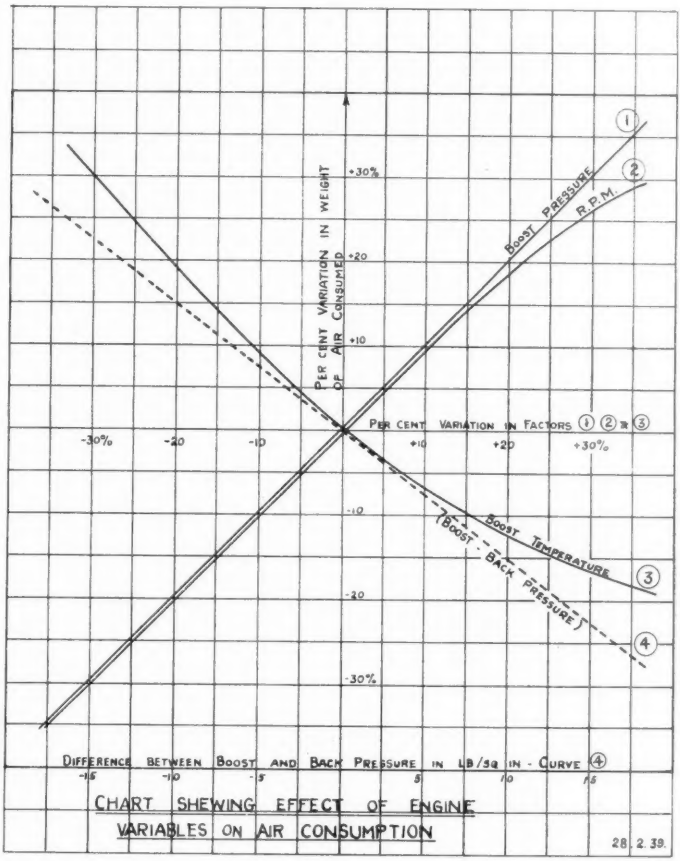

PER CENT VARIATION IN WEIGHT OF AIR CONSUMED
+30%
+20
+10
-10
-20
-30%
PER CENT VARIATION IN FACTORS ① ② & ③
-30%
-20
-10
+10
+20
+30%
BOOST PRESSURE
R.P.M.
BOOST TEMPERATURE
BOOST - BACK PRESSURE
①
②
③
④
DIFFERENCE BETWEEN BOOST AND BACK PRESSURE IN LB/SQ IN - CURVE ④
-15
-10
-5
5
10
15
CHART SHEWING EFFECT OF ENGINE VARIABLES ON AIR CONSUMPTION
28. 2. 39.

FIG. 2.

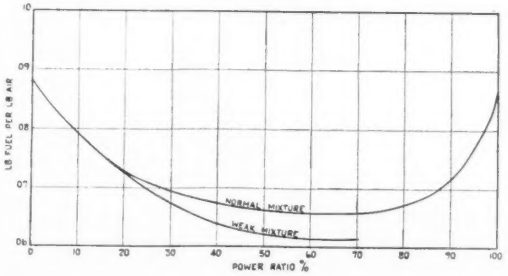

APPROXIMATE CURVE OF THE DESIRABLE MIXTURE STRENGTH.
LB FUEL PER LB AIR
1.0
0.9
0.8
0.7
0.6
NORMAL MIXTURE
WEAK MIXTURE
0
10
20
30
40
50
60
70
80
90
100
POWER RATIO %

FIG. 3.

(3) B.M.E.P. or induction pressure, under the varying throttle conditions.
(4) Fuel density.
(5) Fuel viscosity.

Usually a metering device can be arranged to operate correctly only according to a law involving one variable. In the presence, therefore, of five independent variables it is to be expected that four controls must be provided for adjustment, either automatically or manually, to the continually varying conditions obtained in flight. As explained above, a carburettor will probably have at least four metering devices.

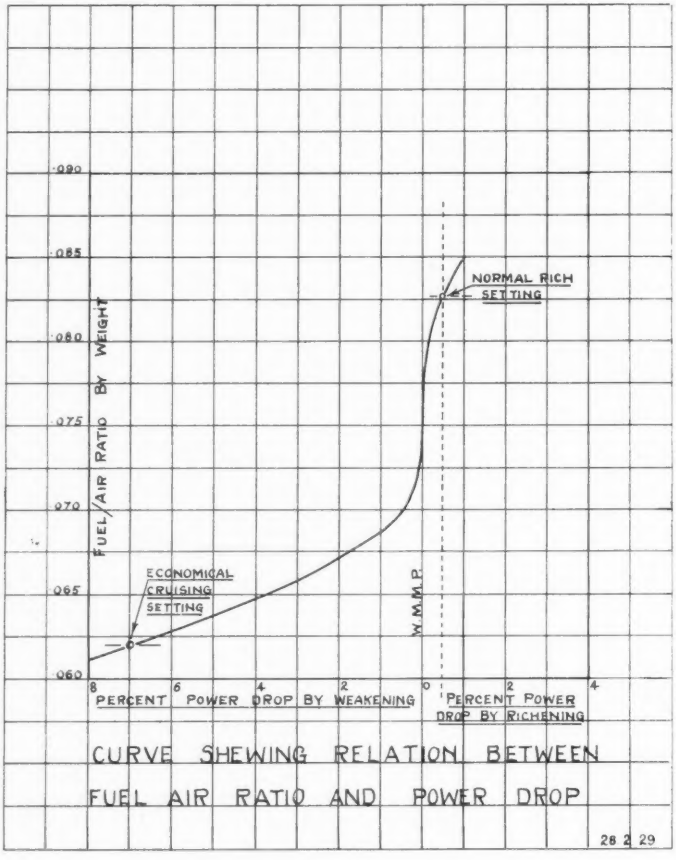


FIG. 4.

Fortunately, many of the variables mentioned are of secondary importance, and may be overlooked without serious loss. Variations in fuel viscosity and density are generally ignored. Atmospheric temperature is rarely considered, even though its influence may not be negligible. The measurement of the air flow by means of a venturi is generally adopted (with corrections) as a function of M.E.P. The mixture control has the duty of adjusting for variations in barometric pressure.

ROLLS-ROYCE "MERLIN" ENGINE.

ROLLS-ROYCE "MERLIN" ENGINE.

CARBURATION SYSTEM.

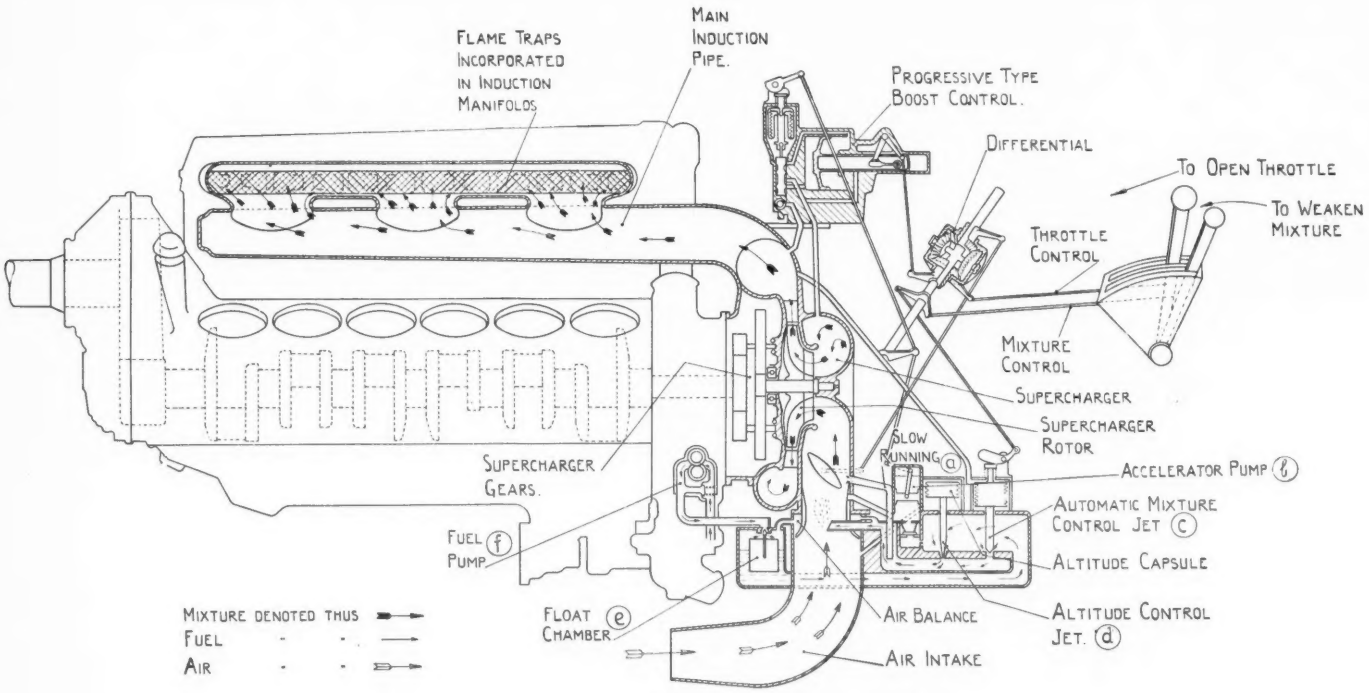
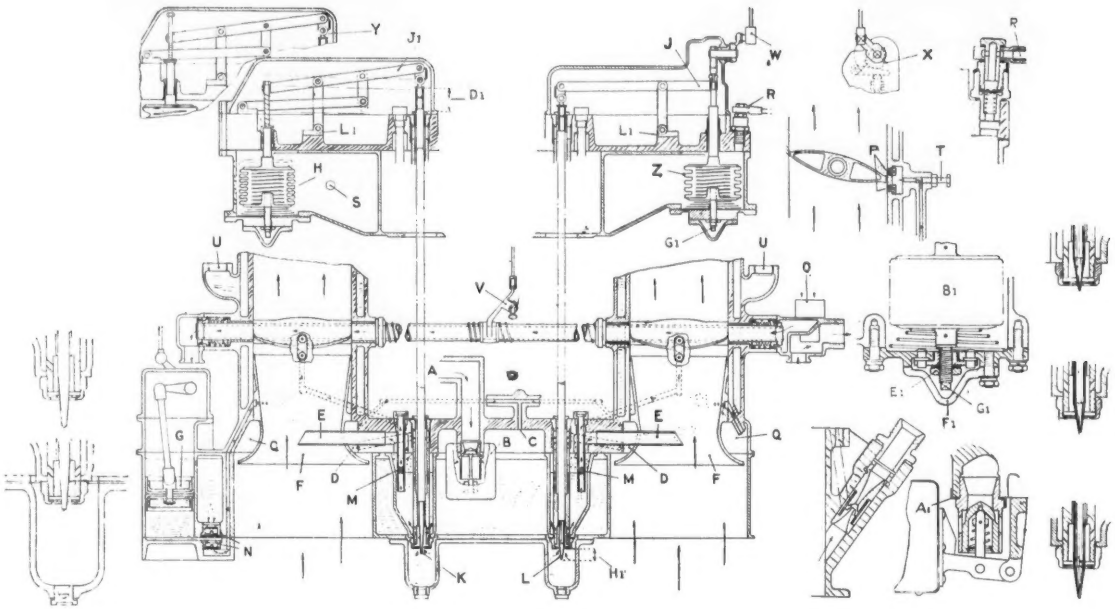


FIG. 5.



DIAGRAMMATIC LAY-OUT OF "MERLIN" CARBURETTER.

A FUEL INLET
B FLOAT.
C FLOAT CHAMBER AIR VENT
D AIR TO MAIN DIFFUSER NOZZLE.
E MAIN DIFFUSER NOZZLE.
F CHOKE
G ACCELERATOR PUMP
H ANEROID FOR AUTOMATIC MIXTURE CONTROL (ALTITUDE)
J MIXTURE CONTROL BY BOOST PRESSURE & TWO POSITION OPERATION
K MAIN JET FOR MIXTURE CONTROL (ALTITUDE)
L MAIN JET FOR MIXTURE CONTROL (BOOST PRESSURE)
M SLOW RUNNING JET
N NON-RETURN VALVES
O OIL FOR HEATING THROTTLE
P SLOW RUNNING MIXTURE DISCHARGE HOLES
Q AIR BALANCE POCKET
R BOOST PRESSURE SUPPLY FOR MIXTURE CONTROL
S PASSAGE TO AIR INTAKE
T SLOW RUNNING ADJUSTMENT
U COOLANT SUPPLY FOR HEATING THROTTLE JACKET
V THROTTLE LEVER
W TWO POSITION MIXTURE CONTROL
X PILOT'S TWO POSITION CONTROL IN "FULL RICH" POSITION
Y FULL RICH POSITION OF ALTITUDE CONTROL IF ANEROID FAILS
Z ANEROID FOR AUTOMATIC MIXTURE CONTROL (BOOST PRESSURE)

FIG.6

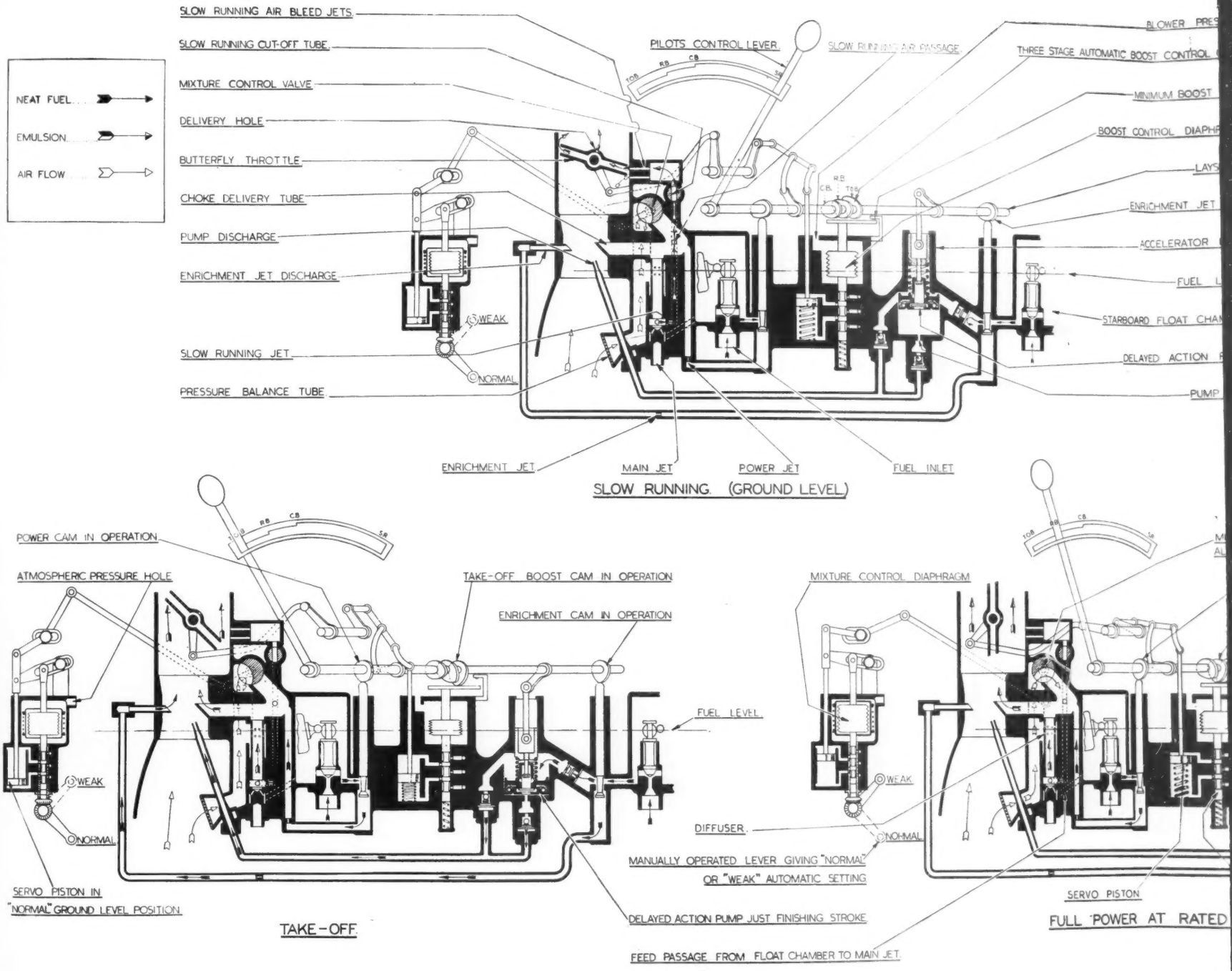


FIG. 7.

Diagrammatic operation of Claudel Hobson 85 M.B. Master Control carburettor.

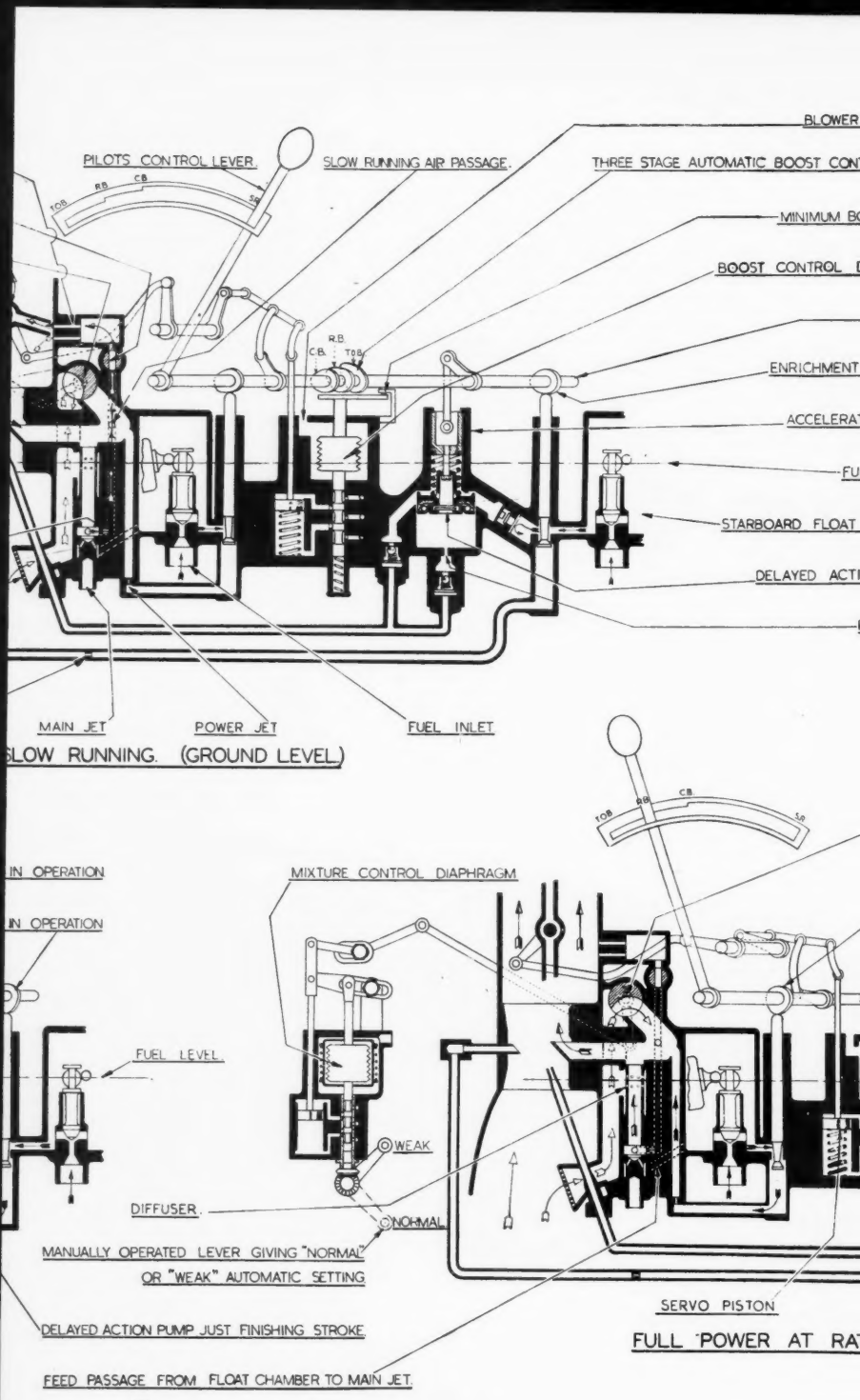


FIG. 7.

on of Claudel Hobson 85 M.B. Master Control carburettor.

BLOWER PRESSURE

OOST CONTROL CAMS

MINIMUM BOOST STOP

CONTROL DIAPHRAGM

LAYSHAFT

ENRICHMENT JET CAM

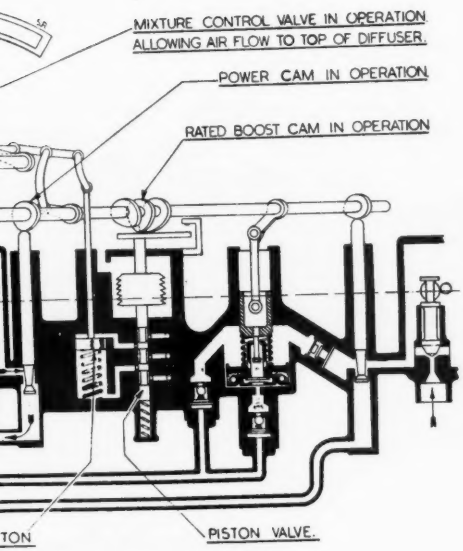
ACCELERATOR PUMP

FUEL LEVEL

OARD FLOAT CHAMBER

ELAYED ACTION PUMP

PUMP JET


MIXTURE CONTROL VALVE IN OPERATION
ALLOWING AIR FLOW TO TOP OF DIFFUSER.
POWER CAM IN OPERATION
RATED BOOST CAM IN OPERATION
TON
PISTON VALVE.

ER AT RATED ALTITUDE.

The intensive development on carburettors in recent years has furnished a number of types which fulfil the requirements of modern aircraft and function on the whole very satisfactorily. The increased demand for improved functional operation has added complicated design features with the introduction of needles, jets, capsules, acceleration pumps, etc.

It is perhaps because of the apparent intricacies that attention is turning towards new solutions and superficially petrol injection seems so very simple.

The added complication in the modern carburettor is the result of having to provide so many variations to metering characteristics of supercharged engines—operating at varying degrees of boost pressure—to the introduction of constant speed airscrews and to the automatic altitude control and enrichment devices. It must be noted, however, that similar devices are just as essential for any of the fuel injection systems.

Description of Modern Carburettors.

Rolls-Royce S.U. Merlin Carburettor.

In Fig. 5 is shown diagrammatically the " Merlin " carburettor system. Air is drawn through twin venturi chokes inducing atomised mixture to flow out of the diffuser tubes and, passing by the throttle valve through the supercharger into the engine induction system, it is distributed to the various cylinders through flame traps.

Functional features of this carburettor are indicated diagrammatically and include :—

(*a*) Slow running—fixed metering orifices.
(*b*) An accelerator pump for quick opening up from closed throttle position.
(*c*) Capsule operated jet for progressive richening at high boost pressures.
(*d*) Capsule operated jet—for altitude control.
(*e*) Float chamber.
(*f*) Petrol pump.

A sectional drawing of the actual carburettor is shown in Fig. 6.

Claudel Hobson A.V.T. 85 M.B. " Master Control " Carburettor.

The Claudel Hobson A.V.T. 85 M.B. carburettor is shown diagrammatically in Fig. 7. It consists of two choke tubes, two throttles and two main and slow running jets which are supplied with fuel from twin float chambers.

A delayed action accelerator pump is interconnected with the pilot's throttle control shaft which also carries five cams, one operating the power jet and coming into operation immediately above cruising boost, another the enrichment jet operating immediately above rated boost, whilst the remaining three govern the three-stage automatic boost control built into the carburettor body.

The mixture strength is corrected for altitude by varying the depression existing above each diffuser. This is automatically performed by a two-stage mixture control, interconnected with the mixture control cocks, and designed to give either " automatic weak " or " automatic normal " cruising mixture strengths.

The slow running mixture is adjustable and is atomised in an air box in each barrel wall before being fed into the hollow throttle.

A sectional diagram of the carburettor showing the controls is given in Fig. 8.

Calibration of Carburettor Characteristics.

When calibrating a carburettor it is usual to determine primarily the requirements of the particular engine on which it is to function by fuel consumption tests with the fuel flow manually controlled and then by suitably proportioning the carburettor diffusers and jets, making the flow follow the ideal curves when

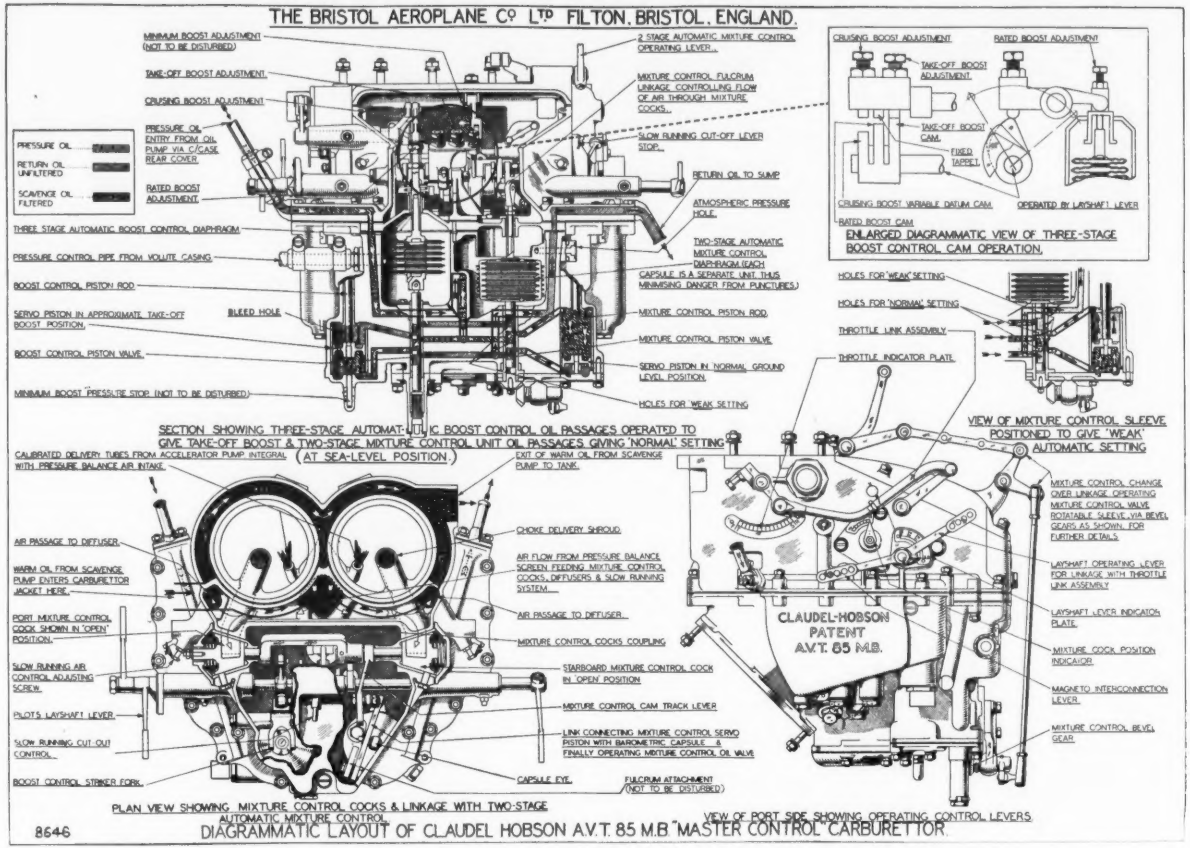

THE BRISTOL AEROPLANE Co LTD FILTON, BRISTOL, ENGLAND.
MINIMUM BOOST ADJUSTMENT (NOT TO BE DISTURBED)
TAKE-OFF BOOST ADJUSTMENT
CRUISING BOOST ADJUSTMENT
PRESSURE OIL
RETURN OIL UNFILTERED
SCAVENGE OIL FILTERED
PRESSURE OIL ENTRY FROM OIL PUMP VIA C/CASE REAR COVER
RATED BOOST ADJUSTMENT
THREE STAGE AUTOMATIC BOOST CONTROL DIAPHRAGM
PRESSURE CONTROL PIPE FROM VOLUTE CASING
BOOST CONTROL PISTON ROD
SERVO PISTON IN APPROXIMATE TAKE-OFF BOOST POSITION
BOOST CONTROL PISTON VALVE
MINIMUM BOOST PRESSURE STOP (NOT TO BE DISTURBED)
BLEED HOLE
2 STAGE AUTOMATIC MIXTURE CONTROL OPERATING LEVER
MIXTURE CONTROL FULCRUM LINKAGE CONTROLLING FLOW OF AIR THROUGH MIXTURE COCKS
SLOW RUNNING CUT-OFF LEVER STOP
RETURN OIL TO SUMP
ATMOSPHERIC PRESSURE HOLE
TWO-STAGE AUTOMATIC MIXTURE CONTROL DIAPHRAGM (EACH CAPSULE IS A SEPARATE UNIT, THUS MINIMISING DANGER FROM PUNCTURES)
MIXTURE CONTROL PISTON ROD
MIXTURE CONTROL PISTON VALVE
SERVO PISTON IN NORMAL GROUND LEVEL POSITION
HOLES FOR 'WEAK' SETTING
SECTION SHOWING THREE-STAGE AUTOMATIC BOOST CONTROL OIL PASSAGES OPERATED TO GIVE TAKE-OFF BOOST & TWO-STAGE MIXTURE CONTROL UNIT OIL PASSAGES GIVING 'NORMAL' SETTING (AT SEA-LEVEL POSITION.)
CRUISING BOOST ADJUSTMENT
RATED BOOST ADJUSTMENT
TAKE-OFF BOOST ADJUSTMENT
TAKE-OFF BOOST CAM.
FIXED TAPPET
CRUISING BOOST VARIABLE DATUM CAM.
OPERATED BY LAYSHAFT LEVER
RATED BOOST CAM
ENLARGED DIAGRAMMATIC VIEW OF THREE-STAGE BOOST CONTROL CAM OPERATION.
HOLES FOR 'WEAK' SETTING
HOLES FOR 'NORMAL' SETTING
THROTTLE LINK ASSEMBLY
THROTTLE INDICATOR PLATE
VIEW OF MIXTURE CONTROL SLEEVE POSITIONED TO GIVE 'WEAK' AUTOMATIC SETTING
CALIBRATED DELIVERY TUBES FROM ACCELERATOR PUMP INTEGRAL WITH PRESSURE BALANCE AIR INTAKE
AIR PASSAGE TO DIFFUSER
WARM OIL FROM SCAVENGE PUMP ENTERS CARBURETTOR JACKET HERE
PORT MIXTURE CONTROL COCK SHOWN IN 'OPEN' POSITION
SLOW RUNNING AIR CONTROL ADJUSTING SCREW
PILOTS LAYSHAFT LEVER
SLOW RUNNING CUT OUT CONTROL
BOOST CONTROL STRIKER FORK
EXIT OF WARM OIL FROM SCAVENGE PUMP TO TANK
CHOKE DELIVERY SHROUD
AIR FLOW FROM PRESSURE BALANCE SCREEN FEEDING MIXTURE CONTROL COCKS, DIFFUSERS & SLOW RUNNING SYSTEM
AIR PASSAGE TO DIFFUSER
MIXTURE CONTROL COCKS COUPLING
STARBOARD MIXTURE CONTROL COCK IN OPEN POSITION
MIXTURE CONTROL CAM TRACK LEVER
LINK CONNECTING MIXTURE CONTROL SERVO PISTON WITH BAROMETRIC CAPSULE & FINALLY OPERATING MIXTURE CONTROL OIL VALVE
CAPSULE EYE
FULCRUM ATTACHMENT (NOT TO BE DISTURBED)
CLAUDEL-HOBSON PATENT A.V.T. 85 M.B.
MIXTURE CONTROL CHANGE OVER LINKAGE OPERATING MIXTURE CONTROL VALVE ROTATABLE SLEEVE, VIA BEVEL GEARS AS SHOWN. FOR FURTHER DETAILS
LAYSHAFT OPERATING LEVER FOR LINKAGE WITH THROTTLE LINK ASSEMBLY
LAYSHAFT LEVER INDICATOR PLATE
MIXTURE COCK POSITION INDICATOR
MAGNETO INTERCONNECTION LEVER
MIXTURE CONTROL BEVEL GEAR
PLAN VIEW SHOWING MIXTURE CONTROL COCKS & LINKAGE WITH TWO-STAGE AUTOMATIC MIXTURE CONTROL
VIEW OF PORT SIDE SHOWING OPERATING CONTROL LEVERS
8646
DIAGRAMMATIC LAYOUT OF CLAUDEL HOBSON A.V.T. 85 M.B. "MASTER CONTROL" CARBURETTOR.

FIG. 8.

the carburettor is working automatically. A typical calibration curve is shown in Fig. 9.

Similarly, manually controlled tests in flight at varying altitudes provide a standard to which the automatic altitude correction system is made to conform. Fig. 10 shows the consumptions of an engine in flight and illustrate how close it is possible for the carburettor to approach the ideal over a wide range of throttle openings and altitudes.

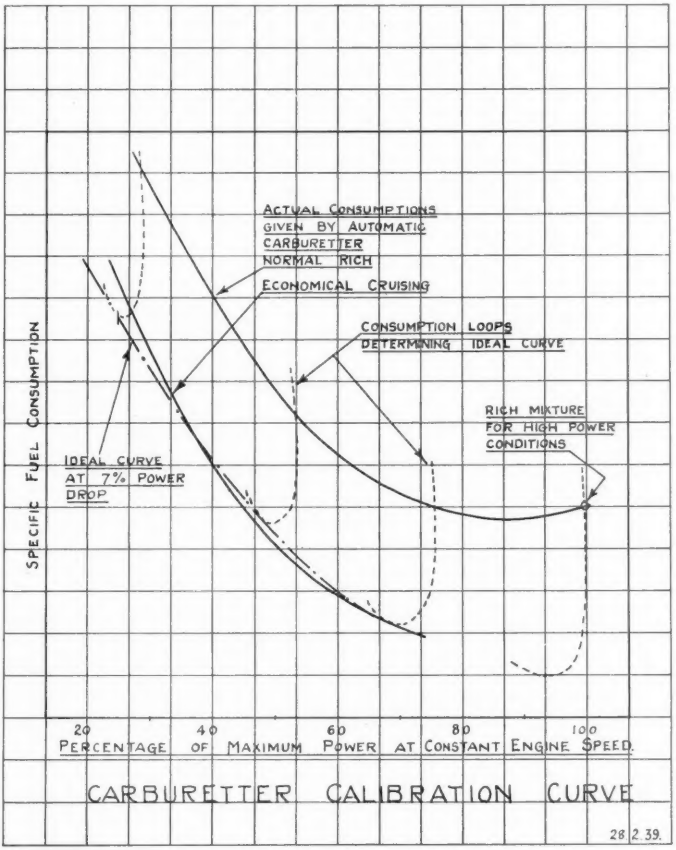


FIG. 9.

When the required carburettor system has been determined no departure should be necessary from the standard in order to maintain the same characteristics on all production engines.

(2) WEAKNESSES OF MODERN CARBURETTOR SYSTEM.

The weak links in carburettor systems, as experienced in test bed development and in aircraft are:—

(*a*) Carburettor icing which invariably stops the engine.

(*b*) Inertia or acceleration forces and negative gravity effect on the float chamber mechanism upsetting fuel flow.

(*c*) Engine cutting out troubles due to back fires in the induction system on take-off, climb, flying in formation and pulling out of a dive, which are usually associated with the temporary upsetting of the fuel metering characteristics.

(*d*) Alteration of tuning due to variation of air flow in the vicinity of the intake.

(*a*) The most common cause of carburettor icing troubles is the building up of ice on the throttle edge by the precipitation of moisture in the air due to the reduction in temperature caused by the evaporation of petrol.

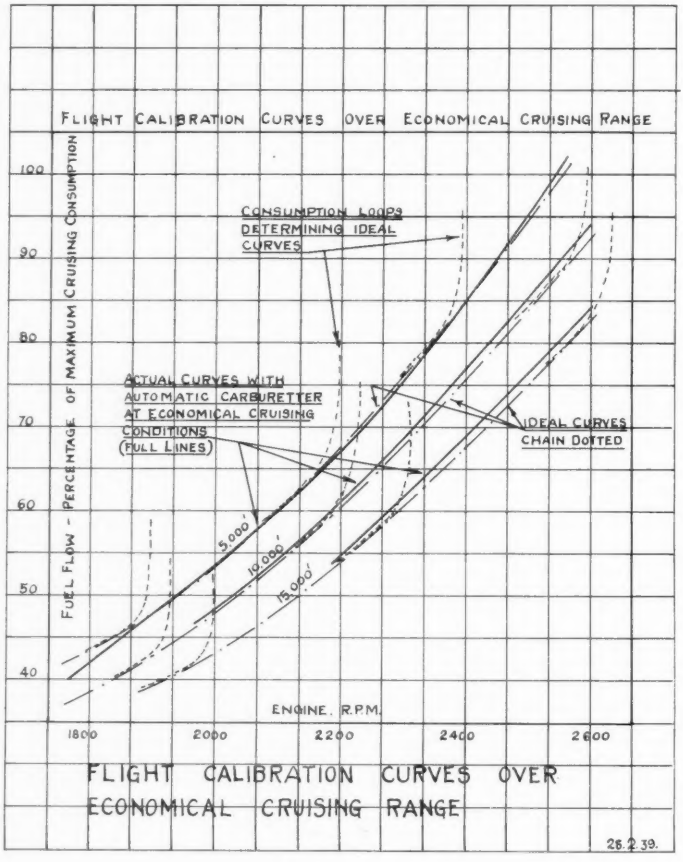


FIG. 10.

Operating with supercharged engines, this trouble is unlikely to occur when the fuel is introduced after the supercharger, on account of the increased temperature by compression. Pressure type carburettors and fuel injection systems may be regarded as immune from icing troubles.

From the point of view of control there are, however, distinct advantages in using a carburettor placed at the inlet to the supercharger. Improved distribution, supercharger efficiency and simplifications are the reasons why it is used in British and American engines.

To introduce fuel in front of a throttle as in a suction type of carburettor is to invite freezing, unless effective artificial heating is resorted to.

The available means of combating freezing are:—

(1) Use of coolant on a liquid-cooled engine by jacketing.
(2) Use of scavenge oil on either air- or liquid-cooled types.
(3) Pre-heating of the air by use of inside intakes.
(4) Use of anti-freeze compounds.

Pre-heating the air, whilst being effective, results in an appreciable loss in power on account of the reduced density effect and is accompanied by a lowering of the fuel detonation limit. It must also have an effect on metering characteristic in relation to the normal cold air intake.

The most efficient method is to maintain the metal temperature around the chokes and throttle at a figure just above freezing point. In practice the increase in charge temperature by this means is hardly measurable. Operating on this principle the engine carburettors, which utilise the hot cooling medium around the choke barrels and the scavenge oil through the hollow throttle valves, have been found to be immune from any freezing troubles.

In cases when freezing troubles cannot be designed out of the carburettor, icing detection and the automatic injections of anti-freeze compounds have been developed (23).

(*b*) For a fuel metering system to function reliably it must be independent, as far as possible, of the effect of machine manœuvres.

The correct metering characteristics depend upon the supply of fuel from the float chamber at a constant head. Existing fuel pumps operating at a pressure in excess of any enhanced gravity effect in conjunction with a reducing valve will maintain a constant delivery pressure to the float chamber under all conditions of flight, but it is not possible to design float mechanism to be independent of the effects of gravity and machine attitude.

The desirability of replacing the float chamber is unanimously agreed, even though experience has proved its remarkable reliability under most conditions of flying. To introduce a device which will maintain a constant head when placed in any position in three dimensions and submitted to violent and erratic acceleration would remove one of the weak links, and is an ambition cherished by the majority of carburettor designers and pilots.

Diaphragm units to replace float chambers are already incorporated in some of the American types and appear to be functioning very satisfactorily. Similar units are being investigated in this country.

(*c*) The prevention of the cutting out of engines is of vital importance and in many cases the cause is due, either directly or indirectly, to some fault or attribute of the carburettor or induction system.

Although the metering characteristics of a modern carburettor can be made to give satisfactory running under all conditions of flight, there are slight differences in engines and machine systems which cause a momentary weakening or richening up of the mixture.

The importance of a momentary change cannot be over-stressed as one blow-back from a cylinder into the common manifold filled with explosive mixture cuts out the others. It is not proposed to enter into the detailed causes of the momentary changes producing cut-outs, but it is of interest to note that by fitting flame traps to the inlet ports this effect is not noticed by the pilot and they are considered essential to ensure reliability against engine cut-out with explosive mixture in the induction pipe.

Timed fuel injection either direct or into the inlet ports has a definite advantage in this respect.

The question might be raised of the effect of vapour pressures on metering characteristics and an examination of the distillation curves (Fig. 11) shows that vapour formation may occur when the relative disposition of discharge jet and metering device is such as to subject the fuel to sub-atmospheric pressures, and

that even when the carburettor is situated before the throttle the question of vapour formation can become critical with excessive heating during operation at altitudes now commonly reached by aircraft. Whilst vapour might reach such proportions as to upset the metering, experience does not appear to show that metering is seriously affected as evidenced by high altitude flights.

(*d*) Experience has shown that differences in aerodynamic features affect the characteristics of air flow in the vicinity of the intake, rendering it difficult to locate the pressure balance orifice so as to ensure the registration of mean pressure under the varying conditions.

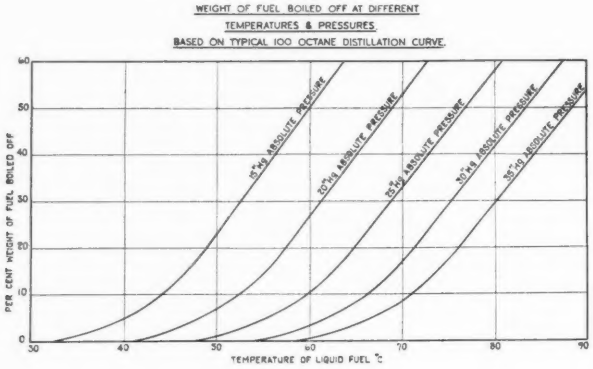


FIG. 11.

CONTINUOUS INJECTION.

Continuous injection might be termed the halfway line. It has certain attractions in that the fuel may be introduced at any desirable point into the induction system; there are no freezing troubles and the float chamber is eliminated. If a low pressure system is employed a rotary form of fuel pump might be used, but it should be recognised that any such system involves a number of difficult mechanical problems and explosive mixture exists in the induction pipe. The fuel metering has to be performed according to the same complicated laws and the only additional apparatus available for this purpose is a pump.

If injectors are to be placed between the throttle and the supercharger they should be mounted so that the jet of fuel does not come in contact with any surface before entering the impeller. Neither fuel nor moisture can cling to the rapidly rotating impeller and by the time the mixture is compressed it has been violently churned and considerably heated so that good vaporisation is ensured and the icing problem is solved, without the application of heat.

Metering pumps are, however, delicate and costly and it might be decided that orifices would be preferable, even though the awkward shape of their discharge curve is one of the carburettor manufacturer's bogies. This difficulty is, however, easier to overcome in the present instance because the pressure drop across the orifice can be freely chosen and the pressure after the orifice can be maintained at a high value by the simple method of a spring-loaded injector.

The air flow may be measured by any method applicable to timed injection and this subject is treated in a later section of this paper. It will, in particular, be possible to abolish the venturi and the absence of any strangulation effect at full throttle will be an asset. The square law between the pressure drop and the air flow at a carburettor venturi has the disadvantage that it causes the greatest strangulation precisely at the only time when no throttling is desired and a compromise must be made between the slow running characteristics and the strangulation at full throttle.

Compared to the timed method, the continuous method when applied to the inlet to the supercharger has the advantage that the density of the gas handled by the supercharger is increased due to the cooling effect of the evaporation of the fuel. This has a considerable effect on the pressure rise across a given blower whilst the power to drive is relatively reduced (Fig. 12) (Bib. 24). Such a gain

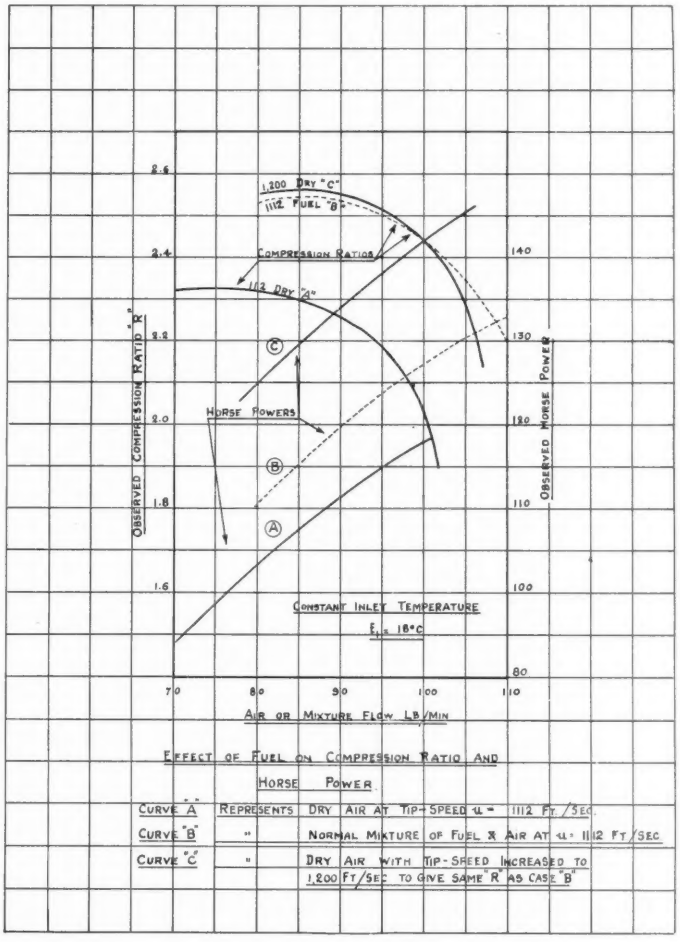


FIG. 12.

would be very welcome to the blower designer harassed by demands for improved performance enabling high octane fuels to be used at increased boosts and greater heights. Unfortunately, the gain depends largely on the volatility of the fuel, which is affected by the temperature and the pressure, and possibly also by the atomisation. The gain obtainable at altitude may, consequently, be expected to be somewhat less than the figures on the curve.

With continuous injection the fuel may be sprayed into the air stream at a high pressure and finely atomised. Good distribution depends, therefore, entirely on

the choice of the position of the injection, on the nature of the jet and on the design of the induction piping. As previously stated, a suitable position for the injector is at the eye of the impeller, the fuel being discharged in an even spray around the opening (Fig. 13).

To obtain a completely uniform distribution round the impeller eye under all conditions of operation would probably be difficult, but the mixing effect of the supercharger should tend to even out slight inaccuracies.

The design of the induction system presents the same difficulties as in an engine with a carburettor. Almost perfect distribution is possible in the case of a radial engine (25), but the induction system of in-line engines is a more delicate problem.

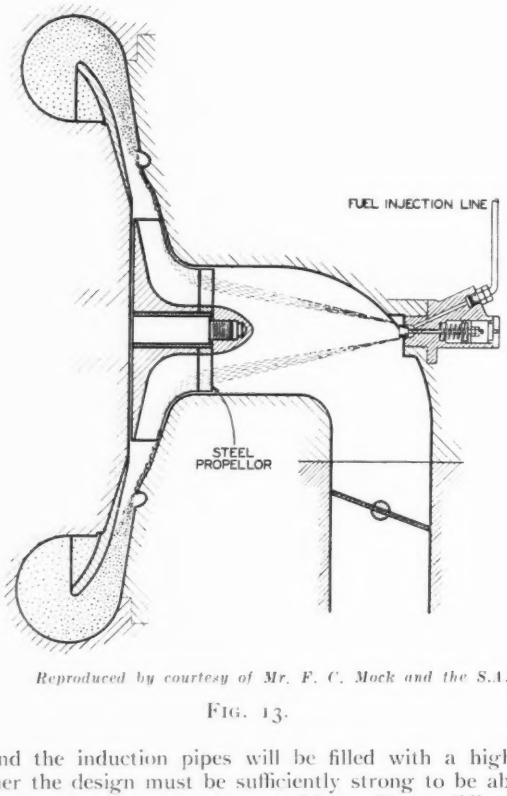


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FIG. 13.

The blower and the induction pipes will be filled with a highly inflammable mixture and either the design must be sufficiently strong to be able to withstand backfires or else flame traps must be provided. These difficulties arise also when a carburettor is used, as does also the impossibility of employing large valve overlaps for scavenging without a prohibitive waste in fuel. The two-stroke cycle, therefore, is not feasible with continuous injection.

Owing to the ever increasing demands to raise the supercharger compression ratios, intercoolers may be expected to be more common and it will be desirable to cool the air before mixing with fuel in order to maintain the efficiency of cooling. The carburettor must in these circumstances be pressure balanced, but it need, obviously, not be heated when situated between the stages of a two-stage blower. From the icing aspect there will, therefore, be nothing to choose between a carburettor and an injector except when only one blower is in operation.

TIMED INJECTION.

The main advantages of this method of injection are:—

(1) Positive metering to each cylinder, enabling perfect distribution to be obtained.

(2) Reduction in the fire risk due to the elimination of backfires and to the possibility of using safety fuels.

(3) Possibility of improved combustion chamber scavenging and cooling by appropriate valve and injection timing.

(4) The freedom from icing.

With timed injection the fuel is positively metered to each cylinder by separate plungers. Owing to the extensive experience which has now been acquired in the accurate metering of small volumes of fuel to C.I. engines, no serious difficulties need be feared in the production of a reliable pump for petrol injection. Nevertheless, it should be recognised that the component is a precision instrument for which tolerances of the order of 0.00004in. may be expected. It will, therefore, be costly, and must be handled and serviced with care. The fuel filters must be highly efficient and may assume large proportions to pass the quantity of fuel.

Fortunately the calibration can be accurately done by the makers and the pump can then be mounted on an engine without special tuning, but an independent calibration and tuning of injector nozzles will be necessary.

The lubrication of the plungers must be carefully considered because of the fine clearances and the poor lubricating properties of petrol. Fuel should not be allowed to escape in quantities sufficient to dilute the main oil supply, and on the other hand oil should not mix with the fuel in quantities sufficient to affect the detonation characteristics.

The possibility of using safety fuels, such as those of the hydrogenated type, is due to the fact that the injectors are placed either very close to, or else inside the combustion chamber. The fuel can be finely atomised and directed towards a warm region. Combustion will be possible if a sufficient amount of fuel vaporises to surround the sparking plug with a mixture of the right composition. American tests have shown (6) (10) that operation by this method is possible, but practical applications have yet to be made. It will probably be necessary to inject an easily volatile fuel for starting.

In all cases of timed injection the fuel has only a very short period in which to mix with the air. It is difficult, therefore, to ensure a uniform mixture. Turbulence is generally employed in an endeavour to obtain an even charge, but it is a difficult factor to control. It cannot be easily investigated systematically, and this may be the explanation why reports on tests by various authorities are so conflicting.

Even with the most carefully controlled turbulence it does not seem likely that for a given boost the same charges can be efficiently burnt as in an engine employing continuous injection. Perhaps the good distribution may more than neutralise this effect and it appears to have done so in tests of the U.S. Army Air Corps (1). The defective mixing would, on the other hand, be an asset during cruising conditions because a weak mixture could then be burnt, provided that the sparking plugs were suitably situated. The ideal would be to obtain a stratified charge for economic operation and a uniform charge for maximum power. This problem has yet to be fully investigated and it may then be found that low grade fuels can be used for cruising operation. Admittedly, the B.M.E.P. obtainable with such fuels is likely to be low, but the difficulty may be overcome by the use of timed injection and the two-stroke cycle.

Tests with large valve overlaps and timed injection have been made by a number of authorities. The N.A.C.A. (26), for instance, found by this method the B.M.E.P. of a four-stroke unit could be increased by 10 lb./sq. in.

The applications of large valve overlaps to aero engines offer a number of difficulties due to the great variations in boosts and back pressures. These may

cause either an excessive loss of compressed air or difficult starting and slow running. This drawback caused the subject to be regarded for long as impracticable, but renewed interest in the exhaust gas turbine has now indicated new possibilities. A property of installations having turbines is that the back pressure on the engine tends to follow variations in boost and to be independent of the altitude. These are precisely the conditions required for good scavenging.

A major advantage of timed injection is the increase it offers in safety even when petrol is used. The amount of inflammable gas is reduced to a minimum and backfires cannot occur. The cutting out of one cylinder due to the failure of both plugs does not put the exhaust gases into communication with a large volume of explosive mixture in the induction system.

Two positions are suitable for the timed injection of fuel:—

(1) The induction manifold close to the inlet valve.
(2) The combustion chamber.

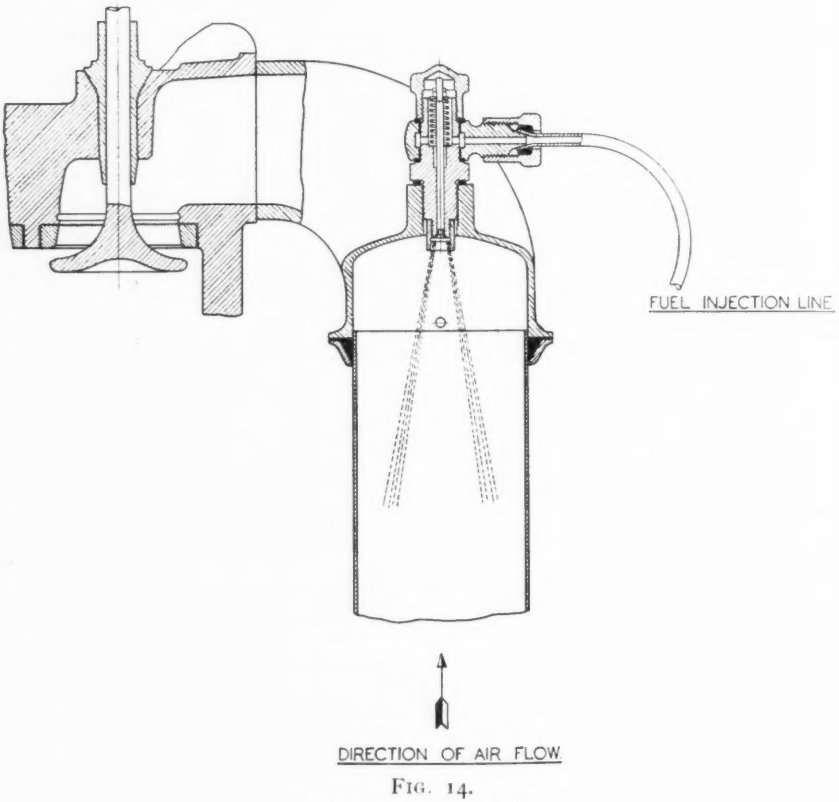


FIG. 14.
Fuel injection to inlet pipe.

MANIFOLD INJECTION.

It is usually a very easy matter to fit injectors to induction pipes and by this method an engine designed for carburettor operation can readily be converted to petrol injection. The distribution between cylinders will be good, but the turbulence may have to be controlled.

This was the method employed in the Bristol " Draco," in the U.S. Air Corps tests, in the Lorraine " Algol," and in all engines " converted " to petrol injection. It has given satisfactory results and it has the advantage that the fuel is not directed against the combustion chamber wall, where it would be liable to dilute the lubricant. On the other hand, the jet cannot be so easily directed towards a hot spot in the combustion chamber and the cooling effect of the fuel is difficult to control. For this reason it is probably not suited for safety fuels.

A characteristic of this method is that the injection timing must be accurate.

Fig. 14 indicates diagrammatically an injector nozzle in position relative to the cylinder and induction pipe.

COMBUSTION CHAMBER INJECTION.

Although this method has so many obvious similarities with Diesel practice, the two processes remain fundamentally different. For the petrol engine it is still an advantage to have a rapidly burning fuel which is difficult to ignite, and the best Diesel fuel remains one that is slow burning and easy to ignite.

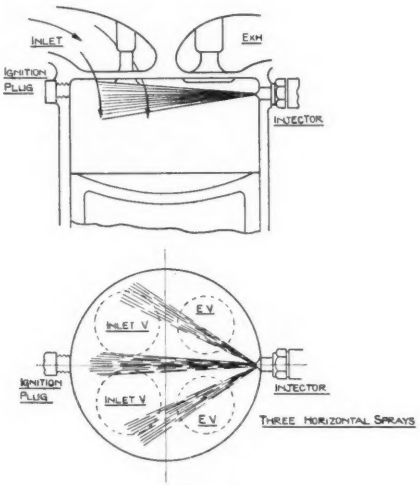


FIG. 15.

Diagrammatic sketch showing direct fuel injection into cylinder.

The mechanical problems involved are, however, much the same. The injector should not dribble. It should produce a jet sufficiently strong to cause good atomisation, but it is highly important that the fuel should not be projected against the cylinder walls, where it might mix with the lubricating oil. The penetration of the jet must, therefore, satisfy certain well defined requirements and it should do so whatever the pressure in the cylinder. The problem is simplified because the injection period occurs during the induction stroke and a longer period is available for mixing than is possible for Diesel operation. The timing is, therefore, not so critical, but turbulence remains an important factor. It may even be stated that turbulence acquires added importance. In a Diesel engine turbulence is an aid in producing an even distribution so that a large charge may be efficiently burnt. Its importance decreases as the load is reduced. A petrol injection engine is far more particular and the consistency of the mixture around the sparking plugs must satisfy well defined requirements. If, therefore, the highest power is required a uniform mixture must be provided, but for

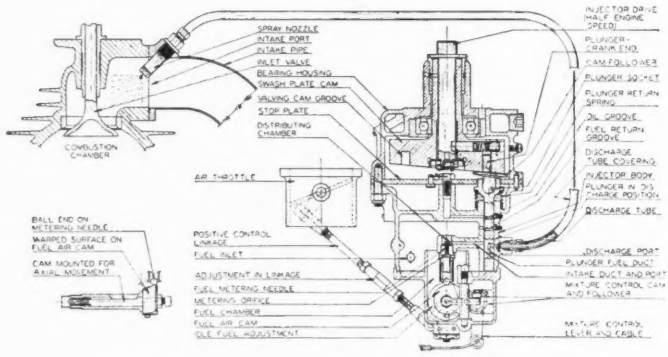
economical operation either the density of the air charge and fuel supply should be reduced in approximately the same proportion, or the mixture should be localised around the plugs and stratification should be employed.

Fig. 15 shows a typical method of injecting fuel into the cylinder.

To meet the above requirements under all conditions of operation will necessitate considerable ingenuity, even though the problem is simplified by petrol injection. Pistons and cylinder heads will probably be specially designed with regard to turbulence. Combustion chambers incorporating pockets and chambers will probably be suggested, but unless a marked improvement can be produced by these methods, it is likely to prove very difficult to persuade the aero engine designer to accept complicated shapes.

Control System.

The duties to be performed by a fuel injection system are the same as those of a carburettor. More freedom is perhaps possible in the design of the metering devices and in the location and arrangement of the jets, but the same complicated



Schematic cross-sectional diagram showing the arrangement and functioning of parts comprising the Marvel fuel injection system

REPRODUCED BY COURTESY OF AERO DIGEST

Fig. 16.

laws dictate the mixture strengths that must be provided. Hopes that fuel injection will greatly simplify the controls are, therefore, unfounded. It may even be stated that the development of the control system has been one of the greatest obstacles to the progress of fuel injection.

In a fuel system with carburettor the float chamber enables the fuel to settle down and the bubbles to separate. In an injection system any vapour formed will persist until after the fuel has been metered. No suction head is therefore allowable, and the discharge from relief valves should be returned to the tank, and not allowed immediately to re-circulate.

The most popular method of measuring the air flow has up to now been to use the throttle position as an indication of the flow. With the Marvel arrangement the throttle is directly connected to the needle metering the fuel (Fig. 16).

The consequence is that in a dive with fixed pitch airscrew and constant throttle position the fuel flow is maintained constant, whilst the higher engine speed causes the air flow to increase. As the engine is not of the Diesel variety this method of controlling the r.p.m. suggests some obvious criticisms.

An improved method was devised for the Bristol " Draco " and an outline of the linkages is shown on Fig. 17.

It will be noticed that a boost control and an altitude mixture control are incorporated. The rig operated well, but the adjustments for tuning offered difficulties. The different characteristics of the throttle, fuel pump, and the automatic controls required co-ordinating, and a number of tests were necessary before this was satisfactorily accomplished by the aid of a special cam on the fuel pump control.

Another method of control is to provide a pump the delivery of which is proportional to the engine speed, and an automatic control for making adjustments to the density in the induction pipe. The fuel flow will then be metered in almost direct proportion to the air flow.

A feature of this method is that the fuel metering is not mechanically linked with the throttle control, and the boost control can, consequently, be designed as an independent unit. This simplifies the mechanical problem, but the more flexible relationship between the two devices must delay the response of the fuel metering to rapid variations in the throttle position. The claim that petrol injection abolishes difficulties due to sudden accelerations has yet to be substantiated, as an additional device may still be necessary.

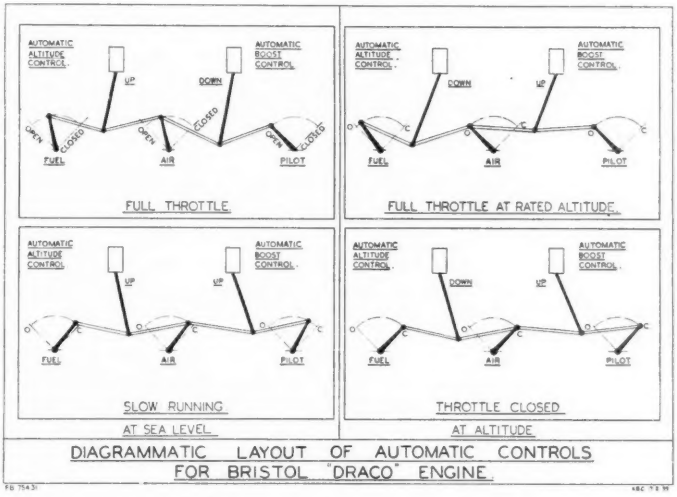


FIG. 17.

Apart from the problem of calibrating the metering device to obey the correct law the design of a control sensitive to density is a difficulty which frequently baffles designers. A pressure control is easy to produce with the aid of a capsule, but the correction which should be made for temperature and the other variables is appreciable and should be made for accurate metering.

As previously indicated the air consumed by the engine is not quite proportional to r.p.m., certainly not directly proportional to induction pipe temperature, is almost proportional to boost pressure, and increases materially with the increase in difference between the charge and exhaust pressures which vary with altitude.

GENERAL SUMMARY.

In view of the mass of experience behind the universal adoption of the carburettor, its displacement by any form of fuel injection system can only be brought about by a convincing demonstration of the latter's general superiority. Although carburettor systems now operate reasonably satisfactorily, there un-

doubtedly exists a number of inherent undesirable features, but it is believed that the few functional troubles sometimes encountered will definitely be eliminated, thus rendering such systems 100 per cent. reliable. This from the pilot's point of view is of primary importance. His next worry in order of importance is the complication of manual control, especially on multi-engine machines. To minimise the number of controls and to ensure minimum fuel consumptions compatible with engine requirements, automatic devices are incorporated and calibrated during flight to suit operational demands. The careful thought and extensive development put into these devices have provided a fairly satisfactory solution in the fully automatically controlled carburettor. At the moment, two controls per engine are arranged in the pilot's compartment, the main throttle and a two position, weak and normal mixture strength, lever, which will probably be eliminated by later development. The absence of material facts based on extensive development rather handicaps the case for fuel injection and leaves a good deal for conjecture.

Such evidence as is available in connection with multi-cylinder engines indicates no improvement in either power or consumption compared with the carburettor system, nor is there any good reason to expect more from the same cylinder compression ratio assuming good distribution with the existing system.

With a supercharged engine, the volumetric efficiency might conceivably be reduced unless the cooling effects of the fuel inside the cylinder during the charging stroke contracts the volume of residual gases. Claims are made of higher powers being obtained from single cylinder tests. Those who are familiar with single cylinder research with carburettor systems will appreciate the large variation in power and consumption obtainable by ringing the changes of valve timing and induction and exhaust pipe ramming effects. Experience, however, shows that these cannot be transferred to a supercharged multi-cylinder engine where common induction and exhaust manifolds are essential.

For this reason the authors would say there is very little to be gained by the way of improvement in volumetric efficiency due to a change in timing to suit fuel injection, if the same simplicity of pipe layout is to be maintained. As regards consumption, the lowest theoretically possible figures have been approached on a carburettor engine having a good distribution system; these are not likely to be improved with the introduction of fuel injection, and though it may be found possible to run on ultra weak mixtures with stratified charges, with the latter system specially designed combustion chambers would be necessary and consideration of these has been outside the scope of this paper.

The layout of a fuel injection system requires considerable care, involving as it does a number of mechanical moving parts and a complicated system of controls. It is essential also that the fuel feed pipes are all of equal length to ensure an equal discharge at each nozzle, although in practice individual adjustment of the nozzle valves may be necessary to obtain an equal mixture strength in each cylinder if the volumetric efficiency of the cylinders is not the same.

On a carburettor system the correct ratio of fuel and air is obtained, to a large extent, by suitable proportioning of the chokes and jets, with automatic devices to give the corrections for altitude and special conditions outside the cruising range. The carburettor, however, requires the added complications of special precautions against freezing in the form of passages and piping to carry the heating medium. Cost and weight are both largely dependent on simplicity and a fuel injection system is certainly heavier and more costly than the corresponding carburettor system. The fine limits involved in the moving parts in an injection pump mean careful manufacture and frequent servicing may be necessary to maintain the accurate metering claimed for this system.

Many hours of development and flying have been carried out on fuel injection, but there is not at present the same experience as has been obtained on carburettors of all types and the undoubted possibilities of fuel injection have yet to be developed fully.

COMPARISON BETWEEN CARBURETTOR AND PETROL INJECTION.

		Timed Injection.		
	Carburettor.	Continuous Injection.	Induction Pipe.	Combustion Chamber.
Distribution	Dependent on induction system.		Excellent.	Excellent.
Atomisation	Dependent on jet characteristics.	Very good.	Moderately good.	Moderate.
Freezing	Can be prevented by special precautions.	Eliminated.	Eliminated.	Eliminated.
Cooling effect of petrol on charge	Considerable.	Considerable.	Small.	Negligible.
Cooling effect of petrol on charge in combustion chamber	Small.	Small.	Measurable in single cylinder unit.	Possible increased breathing due to reduction in residual gas temperature
Effect on supercharger	Improves performance.		None.	None.
Scavenging	Impossible without loss of fuel.		Feasible.	Feasible.
Fire risk (backfires)	Eliminated by use of flame traps.		Eliminated.	Eliminated.
Use of safety fuels	Impossible.	Difficult.	Possible.	Easy.
Aerobatics	Reasonably satisfactory.	Good.	Good.	Good.
Acceleration of engine	Special devices required.	Special devices probably required.	May be satisfactory without special devices.	
Slow running	Sensitive.	Less difficult.	Good, but special devices may be required.	
Cruising consumption	Dependent on distribution.		Reduced by good distribution and possibly by stratification.	
Maximum power	Good.	Good.	Favoured by good distribution, but handicapped by lack of charge cooling.	
Simplicity	No continuous mechanical motions.	Mechanical drive usually required.	Delicate mechanically driven components.	
Tuning	When correctly calibrated is reliable.	Probably delicate.	Performed by pump manufacturer, but controls will require test bed tuning.	
Timing	None.	None.	Fairly sensitive.	Not sensitive.
Weight	Normal.	Possibly slightly less.	Appreciably heavier.	
Cost	Normal.	Probably slightly more.	Considerably greater.	
Controls	Complex on modern supercharged engines.		More complex.	

FIG. 18.

It may assist the audience in drawing its conclusions to have the main facts concerning the systems we have reviewed set out in tabulated form (Fig. 18).

In conclusion, the authors wish to thank their respective companies of Rolls-Royce and Bristol for the facilities accorded them in preparing this paper, the British Air Ministry in according them permission to publish the data presented, and certain members of the staffs of the above mentioned firms for the aid given them in preparing the text and illustrations.

It is wished to emphasise, however, that the opinions expressed are those of the authors, and not necessarily those of either firm.

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Discussion.

The Chairman: They had just heard a most complete review on the question of the carburettor versus direct petrol injection for the modern aero engine, and he would like to congratulate the authors on having provided a paper which would certainly give them all a great deal to think about. He would venture the opinion that certain of the statements were open to debate, and he was not quite satisfied in his own mind with regard to Table No. 18 that quite a dispassionate view had been given as to petrol injection. He remembered in 1909 giving careful attention to an Antoinette V.8 engine belonging to Latham's machine at Brooklands, and being very interested in it. That engine, which provided for petrol injection and

evaporative cooling, first stimulated his interest in petrol injection. In reviewing the subject here and in other countries, he ventured the opinion that in America the work was persisted in actively from 1929 to 1935, and that it was, he believed, dropped chiefly on the question of cost owing to the fact that no really sound automatic air control was evolved. In Germany, on the other hand, 3½ years of intensive development had taken place, with the result that all the high power military engines were using petrol injection. The important factors were that in Germany cost was of no importance economically speaking, and an entirely separate instrument firm had produced a most ingenious automatic air control system.

He was also of the opinion that in considering the petrol injection system one could not take any one factor; it was a number of things of lesser importance, such as starting, slow running and opening-out that all together made an important factor. There were other points he would like to raise, but in his capacity as Chairman he would leave the meeting to have what he believed would be a most lively discussion.

Dr. F. W. LANCHESTER (*Honorary Fellow*): He felt that he had been called upon to open the discussion because he did not know too much about the subject, that being generally considered a sufficient qualification. He had a long experience of carburation and carburettors in connection with road vehicles, but there was a great deal in the paper which was new to him, with regard to which he must plead ignorance. It had been made clear that the problem in the air was far more complex than on the ground. Whilst listening to the paper he had been unable to resist the impression that whereas any fool could design an aeroplane* it would need a transcendental genius to produce a satisfactory carburettor.

The most difficult problem in carburation for motor road vehicles was to obtain test bench results under road running conditions. It was all very well to conduct bench tests and plot power graphs for an engine in which the ignition timing and carburettor were reset, *i.e.*, adjusted by hand, for every change of revolution speed, when under road conditions these adjustments could not be made. One advance in bench testing, for the introduction of which he was mainly responsible, was one by which road conditions were simulated as closely as possible; in this the engine was coupled to a massive fly-wheel, the moment of inertia of which could be varied, to represent the inertia of the vehicle under any desired road conditions. No adjustment (by hand) of the carburettor or ignition was permitted during any test, automatic devices alone being employed. The engine torque was inferred from acceleration data electrically recorded by a chronograph mounted on a side bench. He did not know whether similar methods had been or could be applied to record the behaviour of a carburettor or fuel injection system on an aero engine under conditions equivalent to flight at varying altitude; possibly there may be something said in the paper as to this, but he had not had an opportunity of studying the paper before being asked to lead the discussion; and the paper had been taken at such a "hand gallop" that he had been unable mentally to keep pace with it.

In congratulating the authors of the paper, he hoped they would not take it amiss if he mentioned that never before had he heard a paper read so fast.

Mr. ELLOR: He would attempt to answer the question fairly simply. Fuel injection as applied to aero engines was not quite the same as the Diesel arrangement, where the air and fuel were pushed out of one jet. Solid fuel was dealt with at 3,000 to 4,000 lbs. per square inch, so that the fuel came out solid, and due to the high velocity it became atomised.

Dr. LANCHESTER. The reason it was not volatile was because it was under such high pressure?

* He was once guilty of saying that any reasonable combination of sticks and canvas would fly, if provided with sufficient h.p.

Mr. ELLOR: Yes. Dr. Lanchester was quite right in saying that the adjustment of carburettors for aero engine work had to be done more carefully than for the car carburettors at the present day.

Mr. N. S. MUIR (*Associate Fellow*): In choosing a petrol injection system, from what they had seen from the slides, he thought that one would prefer to handle a single jet spraying into the eye of the supercharger impeller than a number of jets metering small quantities into the induction pipes. With regard to the injection system in relation to sleeve valve engines cutting-out, he would like a few pointers as to the present experience, if any. Does it occur in the same manner as in carburettor poppet valve engines? With regard to separate injection into each induction pipe, it rather puzzled him as to how one would introduce a flame trap system. That was difficult enough on a poppet engine of the radial type. How would it be done in the case of a radial sleeve valve engine? It seemed to him that the only satisfactory way would be to surround the cylinder with an annular form of flame trap and let the petrol vapour from the nozzle spray into that.

Mr. ELLOR: With reference to the first point, where a little more information was wanted on the single jet applying to the supercharger, the paper was really a review of the experience the authors had and what they had gathered from other people. Actually, they had not themselves tried the fuel injection into the eye of the impeller. The Americans had not done a lot, but he thought that the question did afford a fruitful field in which some work should be done. Whether that would be better than going the whole hog and injecting directly into each cylinder time could only show. He was afraid that he had no other information that he could pass on to Mr. Muir. With regard to injection in relation to sleeve valve engines, they had no information, but he could not see that the position would be affected very much. There might be some differences in timing, but even there, as timing did not affect the answer very much, he would say that full injection applied to a sleeve valve would produce the same results as on the poppet valve.

With reference to cutting-out on the sleeve valve, the paper was not intended to discuss what was leading to cut-outs. The cut-out was merely mentioned with regard to blow back that might cause the firing of the charge and causing the engine to stop. It was a question of back firing, and he did not think that there should be very much difference between the poppet valve and the sleeve valve. The fitting of flame traps probably would be a little more difficult when applied to the radial engine. As he saw the matter, it was by no means impossible. One would get exactly the same effect, but would probably pay for it by a little more weight and bulk. What had been definitely proved was that a flame trap was necessary. If the carburettor system operated 100 per cent. from the carburettor point of view, a flame trap was not required. It was only required at a weak mixture which allowed the engine to pop back, or if for any reason the engine was not operating correctly.

Mr. F. R. BANKS (*Fellow*): He congratulated the authors on having produced well-reasoned arguments on the carburation and fuel injection systems. The information contained in the paper was well-balanced, even if somewhat biased in favour of retaining the carburettor. But that was to be understood since, as they had inferred, there was little data available on the latest developments in the fuel injection field.

He personally was still of the opinion that further practical investigation of the timed fuel injection system should be made, particularly for large engines of 1,500 b.h.p. and upwards. The advantages of direct injection were that it eliminated the potential danger of an induction system full of inflammable mixture under pressure and, in his opinion, a further reduction in fuel consumption should be possible because of better distribution to the individual cylinders. Those were particularly important points to consider in the case of large engines having,

say, 24 cylinders. He did not agree that the distribution, particularly in regard to radial engines, was so good as the authors suggested.

The Germans had claimed a reduction in fuel consumption of about 10 to 15 per cent. as the result of going over to direct injection; injecting directly into the combustion chamber. That might be so in the case of the in-line engines in Germany; with these (in-line) engines there was more difficulty with the pressure carburettor, because this type of carburettor was closer to the cylinders and was affected by the pulsations from the individual cylinders. Further, he did not think the Germans had had so much experience as we had, of making a satisfactory carburettor.

From the purely selfish point of view of the fuel specialist, he continued, direct injection would allow single-cylinder units of full-scale engines to be used, for fuel correlation tests, with a better chance of the results being directly applied to the full-scale job; as the cylinders could be treated individually when considering the direct injection system.

There was no practical difficulty in manufacturing the fuel pump unit, and similar pumps were in series production for compression ignition heavy oil engines. Also, there had been little difficulty, apparently, in providing adequate lubrication of the pump plungers, but a small metering lubricating oil pump was probably necessary and should form an integral part of the main pump.

Trouble had been experienced in France and, he believed, Germany, with vapour lock in some injection systems, and a pump between the tank and the injection pump proper was necessary, so that the "inlet" side of the latter was fed under appreciable pressure. It was also necessary to maintain a fairly high pressure in the delivery to the injector nozzle.

He did not necessarily agree with the authors that there was a comparatively small time element in order to obtain proper mixing of the fuel with the air in the case of direct or timed injection. In the case of the carburettor system of the in-line engine, the fuel had to travel along a considerable pipe length before arriving at the cylinders, and despite the relatively high temperatures in the modern boosted induction system, he suspected that the supercharger treated the air and fuel rather as milk and cream were treated in a centrifugal separator, and that there was less charge homogeneity than was usually supposed. Direct injection into the cylinder or, in the case of smaller cylinders with little room to fit an injector, injection into the inlet port directly behind the valve, allowed the fuel to mix with the air under relatively high temperature conditions in the cylinder, over some 250° of crank angle movement, and with a properly placed injector there should be adequate time for effective mixing to take place.

It was, apparently, important that the fuel spray did not hit the cylinder wall, as in that case excessive dilution of the lubricating oil, and also piston scuffing, might occur. In aero engines it was always a difficult matter to get the plugs and injectors where one wanted them; but it was best to position the injector, if possible, so that it would point with a fairly narrow spray angle towards the piston crown, because that warm surface would assist in vapourising the fuel and, in return, receive some degree of direct cooling.

A point in connection with timed fuel injection, which seemed always to be shrouded in mystery or secrecy, was that of the control of the fuel and air to give the correct mixture strengths for take-off, cruising and changing altitude conditions. Nowhere had he been able to obtain specific information on the working of a satisfactory system. He was told in Germany recently that there was very little difficulty in effecting a satisfactory injection control system, but it was not revealed how it was done. He personally had operated one or two injection engines (with the throttle), starting from cold; they had idled very well for an indefinite period, and the acceleration was good when they were stone cold.

The principal disadvantage of the timed injection system concerned the supercharger. As the efficiency of the latter was largely dependent upon the density

of its working fluid, there would be some loss when air alone passed through it, and the supercharger must accordingly be made somewhat larger to deal with the weight of air required, which was at a greater volume; although the elimination of the carburettor choke would help to improve pumping efficiency. In the case of aircraft operating at full throttle at low altitudes, such as low-approach bombers, and fighters which had to deal with low-approach bombers, there would be high temperature boost, so that inter-coolers might have to be fitted in any case; therefore, it would be easier, and much safer, to cool the air than to cool the mixture, and that was why he rather favoured timed injection for the purpose.

Finally, in regard to the carburettor icing problem, he felt it to be so serious, particularly as it affected civil or air-line aircraft, that no effort should be spared to cure and to eliminate the risk. The timed injection system was one way of avoiding icing up, and should be seriously considered on that ground alone. He did not think that continuous injection, into the blower eye, was worth while and it had no particular advantages over the carburettor and, possibly, it had many disadvantages.

Mr. ELLOR: In writing their paper, Mr. Owner and himself had tried to give a quite unbiased review of the subject. But he agreed with Mr. Banks that for many years their work had been centred around the development of an improved carburettor system; so that if unconsciously they had been biased a little towards the carburettor they would perhaps be forgiven. Their point of view was that they would like to know more about fuel injection, because they realised that there were quite a number of points which favoured it. But they had endeavoured to make the point that, unless they were quite sure that the balance of advantages would be with fuel injection, they wished to avoid devoting a lot of brains and energy to the development of that method as an alternative to the carburettor system. However, he agreed that the work already done provided sufficient evidence to warrant a strenuous effort to gain more knowledge of fuel injection as applied to aircraft engines.

Of course, Mr. Banks had had the advantage of flying behind one of the German fuel injection engines; one gathered from him that he was very much impressed, and he seemed to be quite satisfied that a number of matters about which the authors were rather doubtful were really all right. But they required to do some work themselves to verify that. With regard to the point that timed injection was advantageous because the results of work on a single cylinder could be transferred to the multi-cylinder engine, Mr. Ellor suggested that that was so only with regard to the testing of the pump, the nozzle and the jet; but one could not transfer to the multi-cylinder engine the same conditions of power and performance that could be produced in the single cylinder.

In referring to the increased efficiency of the supercharger, Mr. Banks had mentioned a test in which the water did not vaporise. It is true that water does not evaporate very easily, but, with the high compression ratio of the compressors now being used, one could say that 99 per cent. of the fuel was evaporated, and the latent heat was used in cooling the compressed air; that must naturally show up in increased efficiency. The curves that had been shown were the results of actual power measurements from the motor, driving under different conditions, and were not mere deductions.

Commenting upon Mr. Banks' reference to the mystery which seemed to surround the problem of the control of fuel and air mixture strengths, he said that probably, when the German information was disclosed, it would be found that the method was quite simple, and was something which they knew already. It had not been the intention to convey the suggestion that it was difficult to develop a control for fuel injection, and the information required to develop such control was available. What the authors had really wanted to point out was that the control for the carburettor system and the fuel injection system must be very similar.

Mr. H. B. TAYLOR (*Associate Fellow*): With regard to the references in the paper on the use of fuel injection with the two-stroke cycle, he recalled that in the course of some experiments conducted when he was at Farnborough, about 1922, some attempts were made to utilise fuel injection on a single-cylinder engine. A four-stroke air-cooled single-cylinder engine was used and the ultimate object in view was the application of the system to the two-stroke cycle; it was found in that case that no economy in running could be obtained at all by injecting the fuel entirely during the compression stroke. In order to achieve any worth while economies, the fuel had to be injected fairly early in the suction stroke. Therefore, any consideration of satisfactory two-stroke working with such a system was put completely out of court at that time. There had been a lot of development since then, however, and considering that the application of the system to the two-stroke would be very important were it successful, he asked the authors whether they had any information which would show that it could be applied and that satisfactory mixing could be obtained entirely during the compression stroke.

Mr. ELLOR: He had not at his disposal any knowledge as to whether the two-stroke engine could be operated with fuel injection solely on the compression stroke. But the matter was so important that he did not think the development of the two-stroke engine would be discontinued because they could not find a suitable solution for injecting on the compression stroke.

Mr. E. L. BASS (*Fellow*): Although there were several references in the paper to the excellent distribution obtained with carburettor engines of to-day, he was a little doubtful whether it was really good enough for the engines that were anticipated in the future. That point was of tremendous importance in considering the relative merits of the carburettor and the petrol injection systems. There seemed to be very little reliable evidence to prove how good the distribution was in a carburettor engine. It was quite likely that the aircraft engine manufacturers had the information, but this seemed open to question in view of the fact that the authors had had to resort to a N.A.C.A. report to prove their point. In that report variations in mixture strength between cylinders of only 4 per cent. were recorded, but it must be remembered that the fuel used in those experiments was one which met the U.S. Army specification; that specification demanded 90 per cent. distilling below 135°C. The fuel actually used was probably one of about 90 per cent. below 115°. It was a significant fact that aviation gasoline specifications here which permitted fuel of 90 per cent. below 150°C. were, at the present time, a matter of considerable concern on the score of poor distribution to certain American aero engine manufacturers, whose engines were being used in civil aviation on this side.

The capacity to operate at weak mixtures in engines developed to take the best advantage of fuels having octane numbers in excess of 87 appeared to increase enormously the need for perfect distribution; and it was well-known that an engine operating on a specific consumption of, say 0.5 lbs. per b.h.p. hour, permitted much wider variations in distribution without any fear of harm through detonation than did one operating, say, on a consumption below 0.45 lbs. per b.h.p. hour. It was to be hoped, at any rate if 100 octane fuel were to be justified, that considerably lower fuel consumption than 0.45 lbs. per b.h.p. hour was to be obtained; in that instance he was referring to service fuel consumptions and not to test bed or stunt figures. The trend to operate at weak mixtures might, therefore, produce engine conditions which would put a premium on the volatility of the fuel. Very volatile fuels were not only more difficult and therefore more expensive to produce, but were also very much more prone to give rise to vapour evolution in the carburettor and in the fuel lines, particularly under conditions of high altitude flight.

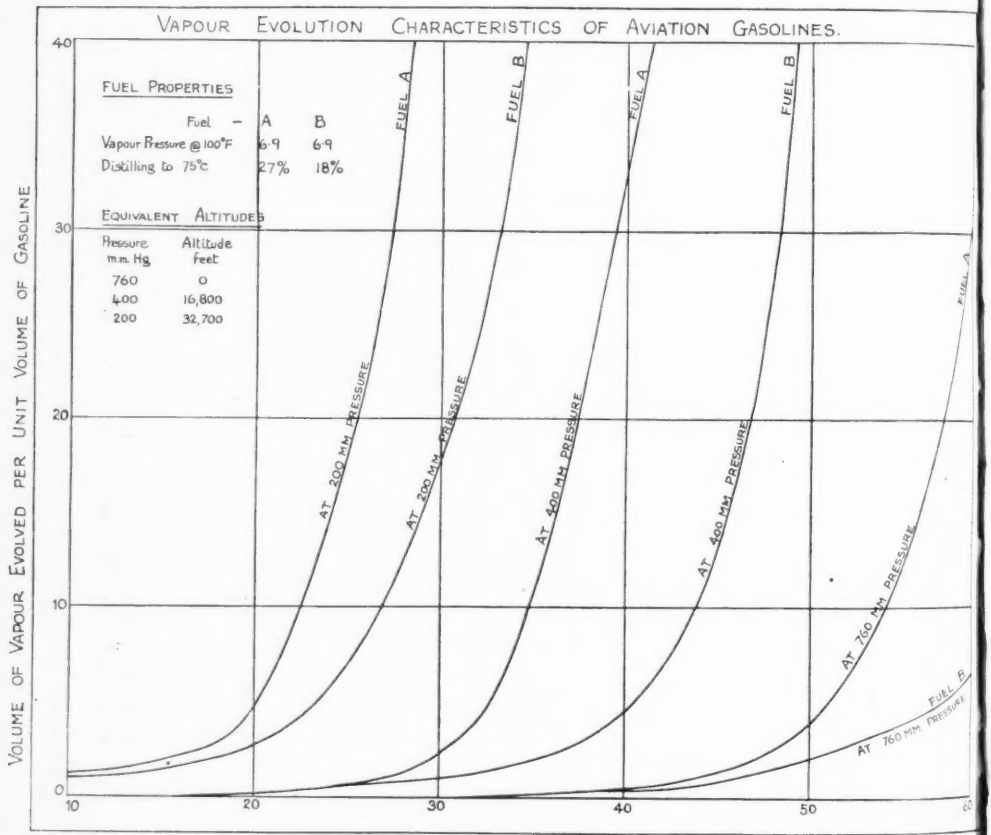
Whilst that aspect of the problem appeared to encourage the development of petrol injection, the advantages of that system might be negatived to some

extent by the requirements for proper mixing of the charge. Therefore, the present standards of volatility might have to be retained or improved upon, or alternatively, increased turbulence would have to be provided. He believed there was a little evidence available to show that fuel sensitivity was considerably influenced by turbulence, and he asked for the authors' comments on that point.

Dealing with the reference, in the section of the paper headed "Historical Review," to the excellent distribution obtained in a carburettor engine in 1935, he asked what method was used in the test described for determining distribution efficiency; in his experiments it was found that the only reliable method was that of making exhaust gas analyses from each individual cylinder.

As to the possibility of vapour evolution in the carburettor, he said that experiments with which he had been concerned had indicated that the rate of vapour evolution of gasoline under conditions of varying pressure and temperature could not adequately be predicted from either its distillation curve or from the Reid vapour pressure. A special apparatus had been developed for determining vapour evolution characteristics, and some results obtained with this on two aviation gasolines are given in the attached curve.

With regard to the mixing effect of the supercharger, it would seem that if the carburettor supplied to the supercharger of a radial engine a mixture which was



very rich on one side and lean on the other, the impeller could aggravate rather than improve distribution difficulties by centrifuging the wet mixture out to one side. It would seem that thorough mixing could only occur really satisfactorily if, as it were, the rich core of mixture supplied by the carburettor were fed axially into the centre of the impeller, a condition which it would appear to be rather difficult to achieve under all throttle conditions. The authors' views on that point would be welcomed.

Mr. ELLOR: In emphasising the importance of distribution, he said that inasmuch as the aim was to achieve maximum economies, they must ensure that the distribution was as good as it could possibly be. The radial engine, with its uniform lengths of pipes terminating in an annular ring, was well set out for obtaining good distribution. In the case of the in-line engine, the problem was more difficult, for one had to experiment a good deal with induction systems in order to get the best results, and even then it was rather difficult to determine whether each cylinder was receiving its right proportion of air and fuel. The old method, of course, was to watch the flames or to take exhaust gas analyses; but the Cambridge instrument was very useful for giving a good guide as to the distribution in each particular cylinder. With the aid of that instrument the authors had been able to improve the layout of the distribution pipes.

He did not know whether Mr. Bass had quite realised that fuel injection did not even up distribution. The distribution of air into the cylinders might be just as bad with fuel injection. All that one could do with the injection was to even up the fuel, and it might be necessary to have quite a different setting for each nozzle into each cylinder, unless one could arrange pipes to distribute the air at a uniform rate to each cylinder.

The point with regard to the fuel volatility, and the difficulty of achieving the volatility required as they advanced in octane numbers, was probably in favour of the fuel injection engine. The authors were working with fairly high octane fuels, but had not yet experienced any difficulty, arising from the volatility of the fuel, in achieving good distribution. Whether difficulties would arise as the octane numbers of the fuels increased, he was unable to say.

He could not answer the question as to whether it was possible to secure even distribution of fuel into the eye of the supercharger, because it was very difficult to measure or to get any indication at all by observation, with such a fast rotating wheel, how the fuel was coming out of the wheel. But one could obtain a very good guide by noting the distribution at the outlet of the supercharger. If a wet fuel were hanging around the wheels, one knew, of course, that it would go into one cylinder or another and would upset the distribution. But, with the high speeds, high compression ratios and the high temperatures they were attaining to-day, it could be accepted that 99 per cent. of that fuel was vaporised. Whether or not there was a homogeneous mixture in the pipes they did not quite know. It might remain as a dense gas and pass along in streams and still get into the various cylinders as a gas, thus giving uneven distribution. But, of course, there were ways and means of evenning that out.

Professor S. J. DAVIES (King's College, London): He congratulated the authors on their presentation of the state of affairs as it appeared to them. He would like to deal with the question of the equality of distribution, and said the curve in Fig. 4 indicated that the distribution was not so good as might be expected for an ordinary petrol. This comparison would, of course, depend on the "chemically correct" air/fuel ratio for the particular fuel used, and this information was not given in the paper. In that connection he wished to refer to the curves published by Tizard and Pye* some years ago, in their analysis of the possible efficiencies of petrol engines: in their curves, the absolute maximum of output was at 15 per cent. rich, but with the curve very flat as it proceeded from correct mixture strength towards the rich side. Using their curves he had

* Empire Motor Fuels Committee Report, Proc. I.A.E., Vol. XVIII.

shown* that, in respect of a single-cylinder engine, in which the question of distribution naturally did not arise, a curve of similar shape, placed vertically below the ideal curve, giving a slightly lower value of efficiency than the ideal, could be obtained. But that, in the case of a multi-cylinder engine in which the distribution was imperfect, the changes consisted chiefly in a horizontal shift of the curve towards the rich side. So that, having such a reference curve, then, in comparing the curve from an actual engine, the air/fuel ratio being known, the relationship of the air/fuel ratio at which the curve became reasonably flat to the air/fuel ratio for correct combustion gave an indication of the "distribution efficiency."

Expressing surprise that little reference was made in the paper to the two-stroke engine, he said that petrol injection offered the possibility of running on the two-stroke cycle at reasonable economy; and surely that was one direction in which we should look for improvement of aircraft engines!

Concerning the possibility of the fuel vaporising in the injection system, Professor Davies said that he and his colleagues had investigated the injection systems of oil engines for some years, and it was quite clear that in these injection systems there were times, under particular conditions, when the pressure in the pipeline between pump and nozzle, for example, was very low and there was definite indication of evaporation of the heavy-oil fuel. It was possible, in order to obviate this and the interference it caused to good injection, to arrange that the pipeline was always under considerable pressure. He would go farther in the case of petrol, and would say that it was desirable to keep the suction line to the injection pump also under considerable pressure. Vaporisation, either in the suction or in the delivery lines, tended to inequalities in the injection.

He felt that, in comparison with the lengths to which it had been necessary to go with the carburettor—and we had had upwards of 30 years' mass experience of carburettors—the authors had rather overstressed the difficulties of controlling the fuel injection system. Further, he suggested that when more experience had been gained with fuel injection systems, some simplification might reasonably be looked for.

Referring to a statement in the paper that petrol was a bad lubricant for a fuel pump, Professor Davies drew attention to a type of fuel pump described recently in some lectures delivered for the University of London by Professor Eichelberg, of Zurich, soon to be published in "Engineering." The system incorporated in that pump was considerably simpler than those generally adopted, and moreover, the clearances of the pump plungers were somewhat higher, and it was stated definitely that the pump would lubricate itself with petrol.

Finally, with regard to changing over from a single-cylinder engine to a multi-cylinder engine, he said the results to be expected depended on which part of the "hook" curve applied.† In the case of a petrol engine at full throttle, the part of the hook curve worked over as the fuel was varied is vertical, so that, in the case of a multi-cylinder engine in which there was inequality of distribution, the mean consumption would be higher than in a single-cylinder engine, but the mean effective pressure would be of the same order. A different kind of inequality might arise in an injection engine, if the weaker mixtures were being worked over—as they invariably are with oil engines; in this case, the effect of the inequality would be small in respect of consumption, but very definite in reducing the output.

Mr. ELLOR: He did not quite follow the remarks of Dr. Davies concerning Fig. 4; but that curve was included in the paper merely to give an indication of the changes of air/fuel ratio between the economical cruising and the normal rich settings.

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* Proc. Inst. Mech. E., 1931, p. 3, Figs. 5 and 6.
† Proc. Inst. Mech. E., 1932, p. 685, Fig. 5.

It had been stated in the paper that the two-stroke engine would not work with a carburettor; it must use fuel injection. But he had no further information on that particular application which he could disclose.

As to fuel vaporisation, he agreed that it was necessary to maintain a high pressure on the delivery line to the nozzle; it was also necessary, in order to avoid trouble, to maintain a pressure on the suction line—and that applied equally well to the carburettor system. A point which perhaps had not been emphasised in the paper was that quite a lot of the troubles met with in aircraft engines to-day were not connected with the carburettor itself, but with the fuel system. If one could not get the petrol to the carburettor or to the injector pump, obviously the engine would give trouble. So that he agreed that it was very necessary to avoid all negative pressures and to try to keep the petrol system under pressure, whether fuel injection or carburation was applied.

A number of fuel pumps were available, of course. The Bosch pump was the one with which they were most familiar, and no doubt the Germans were using it in the systems they had perfected.

Dr. DAVIES: Asked to expand his remarks concerning the change from the single-cylinder to the multi-cylinder engine, said that if one experimented with a single-cylinder engine and wanted to build a multi-cylinder engine as a result, then in passing from the one to the other, if it were a petrol engine with carburettor, one generally used the rich mixture on the vertical part of the Hook curve, and the effect was that there was poorer distribution and lower thermal efficiency, whereas there was not a great reduction of power. If there were inequalities in the injection engine, however, and certainly in the case of the oil engine, then in the multi-cylinder engine the inequalities did not affect the consumption very much, but there was a definite reduction of power.

Mr. ELLOR: He was not sure that that was quite true, because there was no reason to suppose at the moment that with fuel injection one could work with a wider range of mixture strengths, and if there were inequalities the weakest cylinder would impose a limit, from the detonation point of view, as regards the power that could be taken out of it. But if the nozzle were tuned to suit the particular cylinder and its volumetric efficiency, the results might be quite good. But he had no specific information on the matter.

Mr. T. THORNYCROFT: He recalled that as far back as 1908 he had been rather precocious and had actually made a large marine engine running with fuel injection, but he had not been so persistent as he should have been, and he had reverted to the carburettor and the other metering devices. The engine was intended for using heavier fuel and was actually run on heavier fuels, with a pump, and it was run on petrol. But the experiments were not carried far enough with regard to the timing of the fuel injection, and the time element had entered into the problem very much. The size of the engine was 8 ins. by 8 ins., and inasmuch as the fuel was not injected early enough, the engine would not run well to high revolutions. To-day, however, he had become fairly convinced that timed fuel injection was of very great advantage; he could not see the slightest point in the non-timed injection—pumping fuel into the eye of the compressor—for it seemed to him it might have as much disadvantage as the carburettor, without any of the real advantages of timed injection. A very strong point was that, with definite injection into the cylinders, if one cylinder went wrong the functioning of the other cylinders was not upset. He believed that in the paper the authors had laid stress on the fact that with the pump injection it would be very difficult to produce a proper " brain " to control the mixture, and it seemed to him that to produce a " brain " for the pump ought to be easier than for the carburettor, which latter had a great many methods of metering through the different jets. He asked if the authors would agree that in the long run, when we knew more about it, it would be easier to control the petrol injec-

tion pump than the carburettor. We had had very many years' experience of the latter, but even so it was not yet an absolutely perfect device.

Mr. ELLOR: He could not see that it would be any easier to control the petrol injection pump than to control the carburettor, but he did not think that it would be any more difficult. If they could get a fuel injection engine to run slowly and to accelerate without an additional device, then on the whole the fuel injection engine would probably win there by reason of its lesser number of parts; but a lot more work was required yet before they could find out what could be done. On the control side of the carburettor there was not a lot of pieces. The boost control was not considered part of the carburettor, and it was common to both systems. But in an aero engine one required altitude control and the control for varying mixture strengths according to the M.E.P. that was being taken out.

On the motion of the President, a hearty vote of thanks was accorded the authors for their paper, and written contributions to the discussion were invited.

Mr. I. LUSTY (British Airways Ltd.) (contributed): It was with particular interest that he followed the authors' review of the position with regard to petrol injection, as civil airline operators have over many years regarded petrol injection as a worthy project. The reasons for this are twofold.

(*a*) It provides a positive solution to the condition of engine icing and
(*b*) If stratified charges can be obtained, appreciable economies on weak mixture cruising may be expected.

Recently, however, interest in this direction has been somewhat decreased by the very favourable reports received from airline operators using the Chandler-Grove type of carburettor, as this seems to provide a ready-made answer to the engine icing problem.

A vast amount of experience has been gained by the writer's company on icing, and it is considered that oil heated carburettors are unable to provide a complete solution.

As evidence of this the case of an American engine of 450 h.p. may be quoted. These are equipped with a large size oil cooler and a Pratt and Whitney Automatic Oil Thermostat Control. It is observed, however, that under cruising conditions enough oil cooling occurs in the carburettor jacket and the jacket around the blower entry elbow and the pipes thereto, to dispense with the oil cooler, and oil temperatures high enough to operate the Pratt and Whitney oil thermostat only occur during take-off and climb.

It is to be noted that this degree of oil cooling occurs under normal conditions and under icing conditions there is definitely not enough heat available from these sources to eliminate ice formation, and hot air supplies have to be used.

It would be interesting to know whether the condition of heat flow from the oil to the carburettor internal surfaces has been considered by the authors of the paper and whether these heat flow calculations confirm the writer's observations.

In another type of American engine of 900 h.p. operated by the writer's company, the air temperature gauge is in effect the mixture temperature wet bulb thermometer, i.e., it is situated some 7″ after the choke tube necks. Work was carried out to find a reasonable relation between air inlet temperatures and mixture temperatures to facilitate the operation of the pilot's power calculator. It was found that while under normal operation 15 to 20°C. drop occurred through the carburettor, under conditions of rich operation as much as 40°C. was obtained. With heat on, this figure was increased still further, and it was found that to obtain a 30° rise of mixture temperature, 85°C. rise was necessary in the air temperature.

It will be appreciated that such a rise of air temperature would seriously affect power output above the engine rated altitude and might make just the difference between safety and otherwise in crossing mountain ranges. Again at low altitudes detonation has to be considered, and a recommended procedure for take-off under ice conditions is to apply full heat during the run up and to take it off as

the throttles are opened for take-off, trusting in the residual heat in the system to prevent icing during the initial part of the take-off and climb. The engines are then throttled back and heat applied again as soon as the machine is clear of obstructions.

It will, therefore, be seen that while carburettor icing can be combated by the introduction of hot air, serious disadvantages are encountered, and it is for this reason that civil operators have directed their interests towards petrol injection or alternatively in recent times, to a carburettor of the Chandler-Groves type.

Mr. ELLOR: Replying to Mr. Lusty's written discussion—heating the surface of the carburettor by oil alone is not considered sufficient to prevent ice formation, but as pointed out in the paper extensive experiments show that a carburettor can be immune from freezing troubles by a suitable combination of oil heated throttles and water jacketing.

Mr. Lusty's references to the amount of heat input to the air and the figures quoted, rather confirm the disadvantage of this method. It is, of course, obvious that as the mixture strength is increased the latent heat taken out of the air is greater, resulting in a much lower temperature.

To prevent ice formation in carburettors, the best solution would appear to be shielding the air intake in such a way as to prevent the heavier molecules of water passing in and supplying the necessary heat to the walls of the carburettor, which would deal with the moisture in suspension in the air.

Mr. L. KEULEYAN (contributed): The first direct fuel " turpentine " injection motor was certainly that of Robert Street dating back to 1794 and bearing the British patent No. 1983.

The Bellem cycle was patented about 1908 with fuel injection in partial vacuum into the cylinder through an electro-magnetically controlled nozzle, the fuel being under pressure as in the common-rail system.

Then came in 1916 the Junkers opposite piston petrol-injection aviation and marine engines.

We should state that before the " Ares " system comes the French patent No. 609,736 delivered to a Dutch firm dated August 1926; tried out by Krupp, abandoned on account of the high consumption .56 to .67 lb. BHP. hour.

Now as to what concerns direct petrol-injection, in modern aircraft engines he would say that the advantages are so great over the modern carburettor that the extra cost of the fuel injection equipment compared to that of a carburettor, pays for itself in a few months and, particularly for aviation, does not count, as the performance is considerably improved by operating at lower temperature, an increase in power of about 10 per cent. with a saving in fuel consumption over that of the best carburettor of about 10-12 per cent.

Running and maintenance costs are just the same as those of a carburettor, and reliability is equal.

Recent practice dispenses with the lubrication of pump plunger even for high octane rating fuels blended with tetraethyl lead.

He was greatly surprised by the author's statement that the fuel has only a very short period in which to mix with the air—Ricardo's experience on C.I. engines should be demonstrative enough to this end—well what about the mixture formation with the modern carburettor of say 1800-2000 h.p. aircraft engine in which the mixture has to be formed and evenly distributed to the cylinders!

He would like to point out a few particular advantages not mentioned by the authors:—

Just as a C.I. engine, a petrol-injection aircraft engine starts up immediately in the coldest weather, the spray nozzle acting as a primer. Once the engine is started, it keeps on running, whereas with a carburettor, in cold weather, it will usually stall after firing a few times, the fuel from the carburettor not reaching the cylinders immediately because it condenses against the cold manifolds. This

explains that often in cold weather, several starts are needed before the engine keeps running.

The engine with fuel injection will idle and run smoothly at much lower speed than the carburettor engine, even immediately after it has been started and has not yet warmed up.

This makes it possible to warm the engine up at much lower speeds in very cold weather, which is beneficial to the engine.

The engine is smoother running on account of uniform distribution of fuel to the cylinders, resulting in more even power impulses.

Mr. ELLOR: Mr. Keuleyan's remarks are very interesting, and no doubt he has had a good deal of experience with petrol injection.

The advantages he mentions are definitely in favour of the petrol injection engine, but it will be realised that the authors made it quite clear that their experience on such types is strictly limited. It might be pointed out, however, that engines fitted with modern carburettors will start up immediately in the coldest weather and continue to run at reasonably low r.p.m. This, of course, necessitates an efficient induction priming system, in conjunction with a satisfactory slow running device on the carburettor.

THE FUTURE OF FLYING*

By H. E. Wimperis, C.B., C.B.E., Hon. D.Eng. (Melb.), F.R.Ae.S.
President of the Section.

The Presidential Address to the Engineering Section of the British Association provides each year an opportunity for a survey of some aspect of engineering science which happens to be of especial importance at the time it is given, and often one which the experience of the President of the hour may chance to render especially appropriate. My subject to-day is "The Future of Flying." Of its importance at the present time there can assuredly be no doubt. Aviation is surveyed by the public with a tempered pride—Pride, it is true, in man's achievement, but Apprehension, it is equally true, as to the use which is being made of it.

The aspiration towards winged flight was expressed, I submit, with great wisdom when, more than two thousand years ago, the Psalmist avowed his longing for "wings like a dove!" How wise a discrimination is revealed by the poet's asking not merely for the power of flight but that his wings shall be "dove-like." For the space of a generation mankind has possessed the power of flight—a marvellous scientific and technical triumph but, alas, incomplete. Brilliant as was the work of the brothers Wright, the crown of achievement will not be truly won until a grateful mankind sees that the wings gained are the wings of a dove and not those of a bird of prey.

This is the challenge to our age. One generation has solved the mechanical problem, leaving it to the next to solve the moral one.

Ever since man inhabited the earth he has lived not by his physical powers, which are slight, but by the exercise of his wits. Every new invention he has made has had its warlike use as well as its peaceful purpose, and each has challenged his wits to ensure that good rather than harm shall result from the new discovery. To bend the newest invention of all, the conquest of the air, to the service of mankind is now his great task. In it, success is essential lest we presently find that it is the air that has conquered mankind rather than mankind the air. Before we can regard the conquest of the air as achieved we must control the warlike menace.

In our own technical field, we as engineers have long been used to responsibility, to pioneer work, to expert status. But when it comes to the social application of our inventions, we are responsible not in our capacity as engineers but as ordinary inexpert citizens: and here we have been very conscious of our amateur status. We are not experts in the social application of our work; and we are but a handful among millions. This has been the view of the last generation—though held with increasing uneasiness, as the misuse of our inventions has become more apparent.

But it is possible that the conditions which formed this view are changing? May it be claimed—I think it may—that we as engineers, as technicians, have an important contribution to make towards the peace of the world?

I believe that the scientific advances of the present time, and their probable development in the near future, will help us to solve, and not to aggravate, our central problem—the task Lawrence of Arabia spoke of as "the biggest thing to do in the world to-day"—to bend the newest invention of all, the conquest of the air, to the true service of mankind.

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* An address read before Section G—Engineering—of the British Association for the Advancement of Science at Dundee, August, 1939, and reprinted by kind permission of the Association and the author.

Mechanical flight was achieved when Wilbur Wright flew in December 1903 in that odd-looking machine now so proudly housed in the Science Museum at South Kensington. It certainly does look a queer machine to modern eyes. Although the engine weighed 180 lb. it gave but 12 h.p.! Of course it was natural that this, like all the other early aeroplanes, should be built with two pairs of wings. Engineers were well accustomed to carrying bending moments by a form of girder construction having an upper and a lower boom, and in the biplane form of construction the loads could be carried in this familiar way. Such early trials as were made of the monoplane type merely seemed to confirm the idea that a strong wing structure could not thus be found, and the biplane became the accepted type. Speeds in those days were low, and even long after the Great War it was thought that the attainment of high speed would be mainly a matter of putting in more and more engine power. More and more power was accordingly put in. This led indeed to the achievement of higher speeds, but far-sighted designers saw that there was a limit to the extent of progress by this means. But, as a Spanish proverb has it: "When one door shuts another opens." The new door in this case proved to be the streamlining of the external form of the craft as a whole.

That the cleaning up of the aerodynamic structure could carry performance much further than had hitherto been realised, and do so without any increase of engine power, was first clearly pointed out, little more than ten years ago, by Professor B. M. Jones of Cambridge. This required that all excrescences should be removed, and of these some of the worst were the interplane struts and wires. When that had been achieved it was realised that much of the equipment hitherto carried externally, especially in military types, must be put inside, and with that attained, after a severe struggle, there arrived the modern streamlined aeroplane with its undercarriage, and even its tail wheel, retractable into the body of the structure. What yet remained was attention to those external surfaces scrubbed by the passing air stream. Here guidance was given, curiously enough, by the experience of sailplane pilots, who had long found that a much better gliding angle was attainable when the surfaces were not merely made smooth, but were carefully polished, and even dusted before flight! At the time these minutiæ of housemaid's care seemed fantastic, but experience, both within wind tunnels and without, showed that the sailplane pilots were right and that protuberances on a wing no more than a thousandth part of an inch high produced a measurable drag.

Flying To-day

The consequence of these and other changes in design from the original Wright machine brought a steady growth in speed, which during the last score of years has increased by an average of well over 10 miles an hour in each year.

This overall increase in aeroplane performance is indeed impressive: in speed from the 31 m.p.h. of the Wrights to the 469 claimed to-day! Behind the change in external characteristics there have been internal changes of an equally important character, such as the increase from the Wrights' wing loading of $1\frac{1}{2}$ lb. per square foot to the figures of to-day when 20 to 30 and 40, and even more, are common. There has also been an equally impressive change from the modest engine power of the Wrights to the four-figure powers of modern practice.

So far as growth in altitude and range of flight are concerned, further progress must depend chiefly on improvements in the present-day materials of construction, or in the discovery of entirely new ones. At the moment dural is found best, not because it has any higher ratio of strength to density than alternative materials, for in that respect it differs little from steel, or even from cotton or reinforced plastic; but because in comparison with steel its lower density (little more than a third) enables thicker and therefore stiffer and more fool-proof sections to be used. But, as in the case of steel construction, the

sections have to be fastened together with innumerable rivets (more than a million in one "Golden Hind"), and this time-absorbing process is both intricate and costly. If some improved reinforced plastic could be used instead, the path of the manufacturer, once he had learned the art, would be much simplified.

Speeds have grown because of the smoother shapes used in construction and through the greater engine powers provided. Can speeds continue to rise indefinitely? We may have gone almost as far as we can in using ship-shaped forms, though we still know very little about the possibility of ensuring an increase in the extent of the laminar flow of the air over the surface of wings or body: if this could be done the resistance would drop considerably. So far as prospective increases in engine power are concerned that is little publicly revealed in these days, but one hears of testing plants being adapted to deal with engines of no less than 3,000 h.p. apiece. But even with these increases a definite speed limit is being approached—not one imposed by the laws of any State but by the laws of Nature. As I pointed out two years ago in a Presidential Address to the Royal Aeronautical Society, there is good reason to believe that although speeds of 500 m.p.h. may be attained, it is unlikely that 600 will be much if at all exceeded, for the latter figure is some 80 per cent. of the speed of sound, and when the latter is approached the drag rises to a level far ahead of any prospective engine improvements. Although nothing in the physiology of man forbids even higher speeds, as witness the high orbital speed of the earth on which we all live with some measure of tempered comfort, there is soon imposed a physiological limit if high speed is combined with rapid manœuvre. If the latter is required then the speed must be controlled to suit the conditions. Only the future can reveal how the balance between the two will be struck.

No simple summary can be given of what has been done as regards engine development, for great as has been the change from the fifteen pounds per h.p. of the original Wright engine to the one pound, and less, of to-day, one remembers that in this one respect the engines of the last Schneider Trophy Race were as meritorious; where the latter were much below modern standards was in their lack of reliability when working at this power ratio. To-day's engines run without attention for hundreds of hours, a very different matter from endurance for a short race.

Even if engines of 3,000 h.p. may be said to be in sight they are still some way from achievement. Progress depends not only on the skill of the engine designer and the metallurgist, but on the ingenuity of the industrial chemist in producing his remarkable fuels, wonderful alike for their uniformity of quality and for their ability to resist detonation even when employed in engines of very high compression ratio.

The outstanding constructional change to-day is the employment on a large scale of the sleeve valve, particularly as developed by the great Bristol firm. This has the impressive merit of only needing half the component parts of the old type poppet valve engine; moreover it is found that, with a given fuel, it can operate without detonation at an appreciably higher compression.

Engines to-day run safely at far higher speeds than of yore, and they are cooled in different ways and at a much less expense in air drag than used to be the case. In fact at the highest speeds the drag offers some theoretical promise of being replaced by a small thrust! A new cooling problem will arise, however, when pusher airscrews become as common as they will once their use is shown to afford a means of substantially decreasing wing drag.

Improvement in load carrying capacity depends also on improvements in materials, though it is fair to designers to record the progress made in reducing the percentage which the structure forms of the total flying weight in modern aircraft. Nowadays as good a figure is shown for this in large flying-boats as

in landplanes, a remarkable achievement. The flying-boat used to be thought of as slow and heavy, but to-day it holds its own, in efficiency, whether aerodynamic, structural, or economic, with any other mode of flight.

The flying-boats of to-day represent a great technical advance in quality over their predecessors of ten, or even five, years ago, but they have not yet shown any marked advance in size. The fine fleet of Empire flying-boats is made up of 20-ton units; the new Short "Golden Hind" class for the Atlantic weigh 33 tons apiece; the Boeing "Yankee Clipper" has a total weight of nearly 40 tons; but the Dornier D.O.—X. which long preceded them ran to 50 tons laden. On the other hand there has been a great gain in speed and in carrying capacity. The Boeing boat, for instance, is reported to carry 10,000 lb. of load over and above its 4,000 gallons of fuel: as this amount of fuel will weigh 30,000 lb., this makes a total load of 40,000 lb., or almost exactly half of the total flying weight, the same as for the "Golden Hind," and a truly remarkable percentage. The improved Empire flying-boats intended for the Atlantic crossing are planned to take-off at a flying weight of about 20 tons and to take 3 tons of additional fuel after they are air borne—by supply from a flying tanker on Sir Alan Cobham's scheme: this will increase the load on the wings from 30 to 35 lb. per square foot and may be regarded as a first step towards what could be done with wings specially designed and stressed for high loading. The "Golden Hind" class is designed for a range of 3,400 miles without refuelling, and this with full load. Its early programme may include a survey flight along the route to Latin America.

An attractive development in flying-boats is the provision in the Dornier D.O.26 of retractable wing-tip floats which fold inwards into spaces in the wing. This is a 20-ton machine with two tractor and two pusher airscrews. It is a promising move in a very much desired direction. The remaining structural feature to be made aerodynamically clean is the "step" at the hull provided for ease in taking-off. It is no doubt difficult so to design a hull as to be equally efficient whether on the water or in the air, but designers will not be happy until they have satisfied both requirements.

It is naturally impossible in the course of this address to discuss all the many problems in the science of aeronautics which are being investigated at the present time. They are far too numerous and the time too short. But to some of them I must refer. One of great importance and quite fascinating interest is the investigation of the change in the air flow over a wing surface from the laminar to the turbulent state. It is known that if the flow could be kept laminar the drag would be vastly reduced, but it has yet to be discovered how to do this. A step in the right direction may lately have been made at the Langley Field Laboratories, for during Dr. Lewis' recent Wilbur Wright lecture before the Royal Aeronautical Society mention was made of some wind tunnel tests in which a special form of aerofoil gave a drag coefficient figure of only about one-third of that usual. Further particulars will be awaited with interest. Many laboratories and experimental stations are studying this same problem, and, as not infrequently happens in such cases, success once met with, itself creates a batch of new problems. For one thing it is clear that the presence of laminar flow can but be hindered by the use of the tractor type of airscrew now almost universal. It may be necessary to change to pusher designs, and as this will involve a marked rearward movement of the centre of gravity of the whole aircraft, all the stability factors will be gravely affected, to say nothing of the many engine problems also raised.

Other special problems relate to the possibility of having wing areas adjustable in flight by telescopic or other means, to the study of the very considerable increase in the control forces required of the pilot in large machines of high speed capacity, of the special problems raised by variable pitch airscrews, particularly in relation to the landing run, of the advantage at high air speeds of two-speed gear boxes, and of the special problems involved in pressure cabins.

The problem of the rotating wing is in a class by itself. Aircraft so fitted are quite unable to compete in speed with those with normal wings, but they easily beat the latter in take-off and landing. Many types are now in the field, the Cierva, the Hafner, the Kay and the Focke, to mention no others. The scientific problems are largely solved, as are the great mass of the mechanical ones. What is required is such a degree of user as will call for this form of aircraft to be constructed in numbers. When that happens rotary wing aircraft will benefit in their design by that skilled attention from the production engineer which alone seems able to produce results that really look right!

The growth in recent years of the interest taken by the public in aviation, over land and over sea, is most striking. Partly, of course, it is due to the increase in the Air Arm and all that is thereby implied. But there is also a very rapidly growing use being made of the abundant facilities for air travel offered by the Civil air transport services. The United States is often thought to lead the world in this respect—as it certainly does in the use of the automobile—but I believe that in proportion to the size of the population, and that is the true criterion, the total mileage flown annually is larger in Australia than it is in any other single country in the world. And there is good reason to expect that that pre-eminence is likely to continue.

The Future Years

Let us consider what lies ahead in the coming years in respect of speed, size and range. No doubt military craft will go as fast as they can. But since it seems that they cannot exceed 600 m.p.h. much if at all, there is little doubt that speeds between 500 and 600 will become usual. Not so, however, for the Civil Air Services, where quiet, comfort and cost are all-important: here there is good economic reason for speeds to settle down in the 200 to 300 range. In both these classes we seem therefore to be approaching some degree of finality.

Altitude and range are alike in that so much depends on the discovery of new materials of construction and new ways of using them. Steady progress may be expected, though probably nothing sensational unless the use of reinforced plastics be so reckoned. For civil work the advantage of long-range flying depends on the ability to fly by night, and this is advancing rapidly. Radio services are improving and the vagaries of the ionosphere are becoming better understood. . High altitude flying—whether in the stratosphere or just below it—requires the sealed cabin, and it will, I fancy, chiefly be sought by those whose first care is speed and whose lesser concern is cost.

When, however, we come to think of such other factors in the future of flying as the size of the craft, and the wing loading employed, we are concerned with quite other considerations. Size depends mainly on engine power, for there is a limit to the numbers of power units which can be conveniently looked after. Even if we have tractor and pusher airscrews in tandem (and tractor screws may well become unpopular where the highest aerodynamic efficiency is sought), six such pairs may be the practicable limit. This would give us twelve engines, which, at 3,000 h.p. apiece, makes the total power 36,000. At 15 lb. carried per h.p. available this would give a total flying weight of 540,000 lb. or some 250 tons. Such a craft would naturally be a large boat, taking 200 passengers or more; and that is the largest flying craft that can be said to be now in sight, although I ought perhaps to mention that in a lecture to the students of the Royal Aeronautical Society, who alone perhaps might be expected to live to see it, Dr. Roxbee-Cox was bold enough to include an American forecast for a boat of 3,120 tons! But difficult as it may be to foretell accurately the future of the large flying-boat, there can be little doubt that we shall soon see such craft in active competition with their older rivals—which use the surface of the sea—for all rapid passenger transport on the important Atlantic routes.

The future of wing loading is hard to forecast. As has been mentioned, the early Wright aeroplane was loaded to 1½ lb. per square foot. By the time of the Great War this had risen to the neighbourhood of 10, but even Hallam ("Pyx"), writing as prophet a few years later of his vision of a 200-ton flying-boat, did not put it above 8! In the succeeding years, however, the figure has grown gradually until it is now in the neighbourhood of 30; and while loadings of 40 to 50 are talked about for future craft, Sir Alan Cobham has suggested that, provided the bulk of the fuel is added by refuelling in the air from a tanker, loadings as high as 60 or even 70 should not be unattainable. The real limiting factor here is the take-off and the landing. With landplanes, the disadvantage of high loadings is that they lead to great increase in the size and cost of aerodromes, unless this can be avoided by the use of an auxiliary like the Mayo scheme or by some form of catapulting, or by the use of the "tricycle" undercarriage, now so rapidly coming into use. This consequence of high loadings does not apply in the same degree to the flying-boat, but even there it has the disadvantage of requiring the use of natural harbours of large size with not too much local water traffic.

Can one, however, relate these speed ranges of 300 to 600 for military craft, and 200 to 300 for civil, with wing loading, with or without refuelling in the air? We have the relationship that the minimum air speed of flight is measured by the square root of the wing loading. If we assumed the use of such aids as wing flaps, we can calculate for sea-level conditions just what the stalling speed for any given wing loading must be.

For a take-off speed of 100 m.p.h. (i.e., stalling speed of 80) the wing loading would be about 40 lb. per square foot, suitable for civil types having a top speed of, say, 300 m.p.h. (since the take-off and landing speeds would then be about 100). But once in the air a much larger load could of course be carried.

In the case of military types having top speeds of 550 m.p.h. or thereabouts, the landing speed could hardly be less than 150, giving a wing loading of 100 lb. per square foot. It looks therefore as though in the coming years the wing loadings for civil types will go little beyond what is now planned in many drawing offices, but in the case of military types the present-day figures may certainly be doubled unless some new wing arrangement can be discovered which will greatly reduce the loading figure when a landing is about to take place. Rotating wings are the perfect solution for the landing problem, but how to combine them with means for the attainment of high horizontal speed is a problem which the future has yet to solve. The one recent development—or revival—which seens to promise a great advance in safe landing is the tricycle undercarriage: the use of which seems to be almost all pure gain. In a lecture before the Royal Aeronautical Society last year Mr. H. F. Vessey expressed the rather conservative view that although with landplanes of the normal type it is difficult to see any considerable increase in wing loading at landing above about 30 lb. per square foot if present restrictions on landing distances over a barrier are to be maintained, nevertheless he admits that by the use of the tricycle undercarriage the loading might go as high as 40.

It is odd that chance should decide—or perhaps appear to decide—the future of so many forms of human activity. Almost at its birth broadcasting fell into good hands, and the cinema into bad, but aeronautical research, very fortunately, into good. I can imagine a critic remarking that it was not quite all chance: that broadcasting was preserved by the Post Office control over radio, and that organised aeronautical research owed everything to the wise foresight of the late Lord Haldane, who caused there to be created an Aeronautical Research Committee with funds for research workers and apparatus for them to use.

Fortunate it was indeed that research in aeronautics was so wisely led and adequately supported. It was a new science, and one of the few happy results

of the Great War was that it drew into this service some of the most brilliant young scientific men of the day, especially from the universities of Cambridge and Oxford. And this interest held, for even now the leaders are largely drawn from that band of pioneers. In their early work they were happy in their hour, for almost anything that was done was necessarily original and almost any invention was bound to be new: there was little need to consult the records of the past. The Aeronautical Research Committee was, and still is, mainly drawn from these men and those they have trained. With the support and confidence felt in them by the Government, they were able to develop ideas, whether arising from their own ingenuity or from workers and industrialists outside. It was an example soon copied by the United States, and its latest adherent is Australia, the newest country to take up aeronautical engineering as a serious national effort.

It is impossible not to be struck by the stimulus which this specially directed scientific research work has given to other branches of engineering. It represents the spearhead of attack in applied science, since so many of its problems arise from practical conditions of unusual difficulty, owing to the intensity of the desire for light construction combined with strength and durability, and for very high efficiency factors. It is hardly surprising therefore that such apparently non-aeronautical fields as the design of steam turbine blades, of power boats, of industrial fans, of light vehicles should owe so much to the results of aeronautical research.

The Air Arm

Among the world's many political preoccupations there is no more pressing or more intractable problem than that of curbing in some way the universal growth of armaments. It is true that in so far as the product is entirely produced within the country of origin the mere cost is of little moment. One makes armaments instead of making something else, and in the case of a people who loved above all having lots of lethal weapons there would be nothing more to be said, though the taste might be thought odd!

It is not, however, solely a matter of finance, since normal peoples would much prefer the energy directed to armament production to be given to articles of service in civil life such as houses, pictures, sailing-boats, holiday camps and the like; and for the general body of such activity to be guided into channels which fit in with the quantity and quality of the labour available in the country. Moreover, just as a house containing a store of high explosives is not looked on as a happy abode, so there is always a fear that in highly armed international life a trigger in some remote spot may be pulled by accident, or by mischief, with irreparable harm to the whole world.

When some years ago an effort was made to come to an international understanding about air armaments, success was not attained. This was due, it is true, in some measure to the existence of strong professional interests and to the relative lack of attention to the needs of the ordinary man, but it was partly due to the inherent difficulty in the then state of the art of distinguishing between military and civil types. Even suppose, it was asked, that one could abolish all military aircraft, how would one deal with the civil types which could be so easily converted? In those days this was a germane question. But is it now? I think not, and for this reason.

The speeds of military aircraft are now in excess of 400 m.p.h. and will rise still higher. But civil aircraft rarely go faster than 250, and it is doubtful whether it is economically advantageous to have even so high a speed as that. This at once makes a great difference in the types. Again, the comfort and space needed for civil transport tends to produce a design of body which does not in the least resemble military requirements. In so far as the civil types in their really large sizes come more and more to take the flying-boat form, so are

they the less like military types. Perhaps I should say here that I am leaving aside reconnaissance duties and troop-carrying, and thinking mainly of the aggressive type, the bomber.

Hence I submit that, as I suggested in a recent address at Chatham House, the position has been reached when, so far as technical considerations are concerned, an agreed limitation could be set on military production without the effort being nullified by the existence of civil types to which no such limitations applied. It must be remembered, however, that when a political man talks about " parity in the air " he may not really understand what he is saying. What he probably means is equality in offensive force, for mere parity in numbers might be obtained by the absurd equation of putting 100 bombers plus 1,900 interceptor fighters as equal to 1,900 bombers plus 100 interceptors, because both sides add up to 2,000. It cannot worry any peace-loving country, if one of its neighbours builds 1,000 or 10,000 interceptor fighters, any more that it would if that neighbour built immense numbers of anti-aircraft guns and searchlights. In fact, as a gain to the general strength of defence it would be rather comforting than otherwise.

The right way to arrive at a proper balance of air armaments is to seek reasonable parity in respect of bombing aircraft and leave everyone free to build as many defensive aircraft as they care to afford. Civil types would by reason of their low speed be incapable of acting as fighters, and would be speedily shot down if they tried to act as bombers.

There has recently been translated from the German a striking book by S. T. Possony under the title *To-morrow's War*. It is rather difficult to follow, partly no doubt because it is a translation, but the author's object is to show what would be required in respect of men and materials for one year of war of the " total " variety. He assumes a front of 1,000 kilometres, and he arrives at some astonishing figures. He points out that although the losses of aeroplanes in the Great War were but 14 per cent. per month, he anticipates that in a war to-day the monthly loss would rise to 25 to 30 per cent., calling for complete replacement of the whole air force three or four times in the year. For this war Possony estimates a requirement per annum of no fewer than 70,000 bombers and 130,000 other aeroplanes, or 200,000 in all. He then claims that hardly any state could man at one time more than 10,000 to 20,000 aeroplanes and tanks, on account of the exceptional types of men needed and the exceedingly heavy losses. For this and other reasons he concludes that " decisive war is most improbable." He agrees that the world has entered on an era of wars with limited objectives, undertaken with limited means, an era of camouflaged, undeclared wars, the reason being that the nations engaged, being determined not to open the fatal door which leads to universal disaster, seek thus a possible means of achieving their ambitions. Success in a sudden sharp war he thinks impossible. All " total " wars are bound to be long ones. These arguments, if they are acceptable, certainly suggest a pause in the world race to build up huge armaments. The only sure result is financial embarrassment in what should be days of peace, days in which there are so many better things to be done with one's money.

The discovery of the art of flight has certainly raised terrible problems, but it does at last seem as though mankind is beginning to see his way out of the morass. That the laws of Nature impose a speed barrier is a fortunate thing, for that suggests some finality to the development of types, and limits, moreover, any uncomfortable rivalry with the speed of response of the human body. It is fortunate, too, that this speed limit is much above the economic limit for civil machines, for that means that the civil type can easily be defeated if it tries to play the corsair. And it most blessedly happens at the same time that the strength of anti-aircraft defence from the ground and in the air is increasing in effectiveness at a rate that even the most optimistic had hardly dared to hope. Britain, an island in the sea, will become an island in the air!

In my view there will be no reason, once the international situation has cleared, why there should not be an agreed limitation in respect of numbers or tonnage of bombing aircraft—leaving the interceptor fighters entirely aside. It would be but cautious to agree on a limit to the speed of civil types, but as this would merely confirm what economic requirements would themselves suggest, it need be no hardship; excessively high speeds for civil types do not pay, are much more dangerous to passengers, are much more noisy to everyone, and need wasteful forms of air ports.

When this difficulty of our own age has been at last happily solved, we may be very content to leave our successors the even more threatening menace of dealing aright with the problem of atomic energy. This it is not necessary for me to describe. I will only say that in a recent broadcast address Professor Cockroft spoke of an atomic trigger action between the metal uranium and a single neutron which is reported to be capable of releasing a 100,000,000-fold increase in energy! Perhaps there are immense practical difficulties in doing this on a large scale; I earnestly hope there are! For ourselves we may well consider that in our own day we are quite sufficiently occupied with the thoughtful handling of our own special problem, how rightly to guide the Future of Flying.

TRANS-ATLANTIC AIR SERVICES.*

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(*Paper read before the British Association, August*, 1939.)

Introduction.

When the President of the Engineering Section did me the honour of inviting me to read a paper on trans-Atlantic Air Services, I realised that I might be in a slightly difficult position through my association with the composite aircraft, which has been put forward as one solution of the major problem of long range flying.

I have no financial interest whatever in the adoption of the composite aircraft for British trans-Atlantic services. Imperial Airways have the free user for any of their services, and if I have any interest in its adoption it is a purely technical one. Secondly, I would remind you that an engineer who recommends a wide departure from normal practice thereby accepts a heavy burden of technical responsibility. I can assure you that with this in mind I shall not lightly make any such recommendation, but on the other hand, I shall not hesitate to do so merely because I have, with many others, taken a part in this development.

Historical Note.

It was in 1919, just over 20 years ago, that the first successful flights over the North Atlantic were made. In May, 1919, Lieutenant-Commander A. C. Read, of the U.S. Navy, made the first Atlantic crossing by air in a N.C.4 Flying Boat; the crossing was made in stages from Trepassey Bay, Newfoundland, via the Azores to Lisbon, and took eleven days. In the following month the first direct crossing from Newfoundland to Ireland was made by Alcock and Brown in the British Vickers Vimy twin-engined biplane—a military type provided with additional petrol and oil tanks. My first association with Atlantic aviation arose through this flight, because I was deputed to go to Ireland on behalf of the Royal Aero Club in order to verify the aircraft and welcome the crew on completion of their great effort. By flying across Ireland from Dublin I managed to arrive at Clifden about two hours after they had landed. I found that the hull of the aircraft had sunk well into the peat bog upon which they had landed and a certain amount of damage had been done. The seals which I had to examine were inside the pilot's cockpit, and I was astonished to find that I had to dip my arm deep into petrol in order to reach them. The tank had been damaged in the landing and the petrol had not yet percolated away. There was no way of measuring the amount of petrol left, but it was obvious that Alcock and Brown could have flown many hundreds of miles further if they had wanted to do so. My first impression was that the North Atlantic could not be so difficult a proposition after all if it could already be flown with so much margin in hand. I soon realised, however, that the real lesson to be learnt was just the opposite. The fact that so much petrol was left showed what a strong westerly wind the flying had experienced. The time taken for the crossing, namely, 16 hours 12 mins., indicated an average ground speed of approximately 125 miles an hour. Alcock told me that when he realised he was to have so strong a following wind he throttled right down so as to ease the engines as much as possible; he thought his air speed could not have averaged much over 65 m.p.h., in which case the average westerly wind must have been not far short of 60 m.p.h.

* Abridged slightly and reprinted by permission of the British Association and the author.

Subsequent investigations have shown that winds exceeding about 40 m.p.h. are comparatively rare at that time of year, so that Alcock must have chosen an exceptionally favourable day for his crossing. But the fact that such formidable winds were liable to occur was the outstanding lesson to be derived from this great flight, and throughout the succeeding 20 years of gradual progress towards the conquest of the Atlantic this strong prevailing westerly wind has been the dominating factor.

It was some eight years later that Lindbergh made his famous solo flight from New York to Paris. He also derived great advantage from the prevailing westerly wind, and made the distance of 3,600 miles in 33½ hours. He probably could not have gone more than about half the distance in the opposite direction.

In this and the following years various North Atlantic flights were made, some successful and some not, but all the time range and speed were gradually increasing and the day was drawing nearer when serious efforts towards the establishment of a commercial service could be begun. One notable contribution was the first East and West crossing by the German pilot Kohl and his associates in 1928. They made the crossing from Ireland to Greenley Island, Labrador, in 37 hours. Another was the flight of the French pilots Codos and Rossi in 1934 from New York to Syria, a distance of 5,659 miles.

In 1936 several successful flights over the North Atlantic were made by the German airship Hindenburg, but this great airship eventually came to an unfortunate end at Lakehurst where she was destroyed by fire. That disaster brought to an end the attempt to establish a service over the North Atlantic by airship, and it cannot be said that there is at present much prospect of any revival in this direction. The fire risk can perhaps be eliminated at a heavy sacrifice in weight and cost, but, apart from this, the speed offered by the airship is far too low to permit of a successful service in face of the strong prevailing winds. Future developments may conceivably alter the picture, but for the present the airship must be dismissed as a serious factor in Atlantic aviation, and hopes for the future must be based on heavier-than-air aircraft.

It was not until 1937 that the first exploratory flights with heavier-than-air aircraft of a commercial kind were attempted. In that year five return flights between Southampton and New York, via Foynes (Ireland), Botwood (Newfoundland) and Montreal were made by Imperial Airways on Short " Empire " type flying boats.

In the same year, 1937, several return flights between New York and Southampton were also made by Pan-American Airways, these being partly via the northerly route (Botwood—Foynes) and partly by the more southerly route (Bermuda—Azores).

No commercial load was carried on these experimental flights, because it was all the aircraft could do to get the range when loaded to capacity with fuel and oil. But invaluable experience in regard to meteorological conditions and radio requirements was gained and it was on this experience that the present experimental mail service has been based.

In 1938 only one British flight across the North Atlantic was made, namely, the flight by Mercury, the upper component of the composite aircraft, but this flight was significant in that it was the first Atlantic flight made with a commercial load. Mercury was launched from the lower component Maia at Foynes and made the first non-stop crossing to Montreal in spite of head winds averaging about 25 m.p.h. over the Atlantic and from 40 to 50 m.p.h. between Newfoundland and Montreal. Mercury flew on with most of her commercial load to New York, and London newspapers of 20th July were thus on sale in New York on the following day. The return flight was made via Botwood, Horta (Azores) and Lisbon, because no lower component was available on the other side, and with normal take-off Mercury's range was reduced by more than half.

And now in 1939, 20 years after Alcock and Brown's flight from Newfoundland to Ireland, we have the first attempts at regular scheduled services carrying mails.

These were started by Pan-American Airways with their large Boeing 314 flying boats, first by the more southerly Azores route and then later by the Botwood–Foynes route. The service was scheduled as a once weekly service in each direction and the schedule has on the whole been well maintained. The corresponding British service with Short S.30 flying boats was intended to start up on June 1st via the Foynes—Botwood route, but the start had to be delayed for various reasons until 5th August. At the time of writing this paper two weekly services have been successfully completed and there seems every reason to hope that the schedule will be substantially maintained for a period of about two months. After that it must shut down until the elements consent to its resumption next summer.

And so, after 20 years resistance, the Atlantic has yielded a little, but is still very far from being conquered. The stage has not yet been reached when an attack during the winter months can be attempted and much remains to be done before that stage can be reached. Complete success will not have been achieved until a reliable, regular and frequent all-the-year-round service has been established, and no one is really qualified to predict how long that will take. If I had to make a forecast it would not be less than another ten years, and in saying that I am certainly not belittling the great efforts which have already been made, particularly by the pilots and crews who have risked their lives in this great enterprise.

Alternative Routes.

The selection of the most suitable route or routes for the operation of a North Atlantic service is a very complex problem. Many factors have to be taken into account, including weather, length of maximum stage, total distance between the terminals, total time, harbour or airport facilities available, and political considerations.

The extreme northerly route via Iceland and Greenland was once thought to be attractive because of the comparatively short stages involved. It was explored by von Gronau in 1930-32, but any serious thought of developing it has long since been abandoned owing to bad weather, remoteness and inaccessibility of the possible bases, and the long total distances and time involved.

The available intermediate stopping places on the feasible routes are Newfoundland, Bermuda and the Azores. Unfortunately each of these suffers from at least one acute and irremediable disadvantage.

It has been possible through the combined efforts of the Governments concerned to establish in Newfoundland both a marine base and a land aerodrome relatively free from the prevailing fog which is the bugbear of Newfoundland as a whole. But the marine base at Botwood freezes in during the winter months and this renders it unusable by marine aircraft for more than six months in the year. The land aerodrome at Hatties Camp will suffer from the disadvantage of heavy snow during the winter months and although various methods of dealing with this difficulty have been proposed it seems probable that it will be a handicap to regular operations. Apart from these particular considerations it has to be admitted that Newfoundland is in a bad weather area and is likely to be subject to severe ice-forming conditions in the air. This factor seems likely to be a formidable obstacle to regular operations through the winter.

Bermuda offers a magnificent harbour for marine aircraft operations and its climatic conditions are on the whole admirable. The misfortune of Bermuda is that it offers no possibility of establishing a land aerodrome.

The Azores would provide a valuable intermediate refuelling point for Atlantic operations if it were not for the remarkable fact that in all this group of islands there is not a single harbour suitable as a base for marine aircraft nor apparently a single strip of land suitable to form an aerodrome for long range aircraft. There are, practically speaking, only two harbours in the Azores, namely, Ponta Delgada and Horta. The protection offered by either is negligible so far as

aircraft are concerned. Horta has the advantage of geographical position and the water outside the harbour is less exposed than that at Ponta Delgada. For these reasons Horta is the only marine base at the Azores which need be considered in connection with Atlantic services. The frequency with which Pan-American Airways have been able to use Horta during the summer months has demonstrated that the conditions there are on the whole reasonable during these months. It is certain, however, from observations made that the conditions at Horta will on many occasions be impossible for the operation of marine aircraft during the winter months. It is suggested that under such conditions an alternative bay offering sufficient protection can nearly always be found, communication with the base at Horta being maintained by surface craft. It may be possible in this way to maintain a service through the winter, but it appears to me inevitable that considerable delays will be involved and that considerable risks will have to be run. It is difficult enough to run a regular service with marine aircraft when they can land and take-off with certainty at an organised and fixed base, but the difficulties of operating at a variable base without adequate facilities anywhere are likely to prove a severe handicap to anything in the nature of regular services. At various times proposals have been considered for the construction of an artificial harbour at the Azores of sufficient size to give protection for long range marine aircraft, but the cost involved has always proved to be prohibitive and there does not seem any prospect that this difficulty will be overcome.

Various surveys have been made with a view to locating a suitable site for a land aerodrome on one or other of the islands of the Azores, but the results have not been encouraging. The mountainous terrain offers few suitable locations and there is always the difficulty that a site at any appreciable altitude is liable to be enveloped in cloud. It must be remembered that a base for long range operations must remain serviceable at all times or there must be one or more alternative bases available.

These are the characteristics of the possible intermediate positions on the North Atlantic routes. Mention should be made at this stage of the relationship of Eire to these routes. The west coast of Eire is about 350 miles to the west of Southampton which, unfortunately, must be regarded as the home base for British services with marine aircraft. I say unfortunately because Southampton is quite unsuitable for this purpose and with the best will in the world cannot be made suitable owing to congestion of shipping. Strangely enough, however, it is the only base available.

A base on the west coast of Eire thus offered the obvious advantage of reducing the length of the direct crossing to Newfoundland by approximately 350 miles and the Eire Government co-operated in establishing a base on the mouth of the Shannon. During the experimental services of the last two years the base has been located at Foynes, which offers admirable protection for marine aircraft. The new base which will comprise also a land aerodrome is on the opposite side of the Shannon at Rynanna. Thus, although the land aerodrome is not yet completed, this base, to which I shall refer as Foynes for convenience, can be considered as available for future services by either marine or land type aircraft.

It will now be convenient to summarise the stage and total distance involved in the various alternative routes. From the British point of view it is necessary to consider both Montreal and New York as western terminals, because it must be our purpose both to complete the chain of Empire air communications by linking up Canada with Great Britain and to participate in the development of services over the great traffic route between New York and Europe.

In the following table and subsequently in this paper Southampton is taken for convenience as the British terminal base for either marine or land type aircraft. It is not implied that Southampton would necessarily be the base for land type aircraft, but the figures would not be substantially different for an alternative base nearer to London.

(1) Southampton—Montreal Routes.

Route.	No. of Stages.	Longest Stage (miles).	Total Distance (miles).
Southampton—Montreal direct	1	3,200	3,200
Southampton—Foynes—Botwood—Montreal ...	3	2,000	3,230
Southampton—Horta—Bermuda—New York—Montreal	4	2,070	4,750
Southampton—Lisbon—Horta—Bermuda—New York—Montreal	5	2,070	5,200
Southampton—Horta—Botwood—Montreal ...	3	1,575	3,970

(2) Southampton—New York Routes.

Route.	No. of Stages.	Longest Stage. (miles).	Total Distance. (miles).
Southampton—New York direct	1	3,400	3,400
Southampton—Foynes—Botwood—New York...	3	2,000	3,420
Southampton—Foynes—Botwood—Montreal—New York	4	2,000	3,550
Southampton—Horta—Bermuda—New York ...	3	2,070	4,420
Southampton—Lisbon—Horta—Bermuda—New York	4	2,070	4,850
Southampton—Horta—Botwood—New York ...	3	1,575	4,150

Neither Foynes nor Botwood are far off the Great Circle routes to either Montreal or New York, and it will be seen that calls at these intermediate bases do not materially increase the total distance to be flown. Such calls do, however, appreciably increase the total time involved, because every refuelling stop involves a minimum loss of time of, say, half an hour to an hour, and is a potential cause of considerably more loss of time due to other causes, such as bad local weather or surface conditions, mechanical trouble, etc.

I have mentioned in referring to the Azores that if the terminal of a long stage does not remain serviceable at all times there must be an alternative base within reasonable distance. Otherwise, if the aircraft is delayed by exceptionally bad weather or some other cause, it may be unable to make a safe landing before its depleted reserve of fuel is exhausted. This argument applies with particular force to Newfoundland which must be reached after the 2,000-mile ocean crossing, and points to the great difficulty which is likely to arise in the regular operation of land type aircraft to Hatties Camp during the winter months.

The Azores—Bermuda route would offer a good alternative for winter operations, with a maximum stage substantially the same as that of the more northerly route, if only reasonable harbour facilities were available at the Azores. Unfortunately such facilities are not available, and although some people think it will be possible to maintain a regular service by using alternative bays according to the local conditions, my own view is that such operations will not prove to be sufficiently safe or regular to make them worth while.

This same difficulty of lack of facilities at the Azores is a bar also to the establishment of a regular service from Southampton to Montreal or New York via the Azores and Newfoundland. As regards maximum length of stage, this route is at a very substantial advantage over any alternative route. It will be seen from the above table that the maximum stage is 1,575 miles against the 2,000 miles of the Foynes—Botwood route and the 2,070 miles of the Azores—Bermuda route. The Azores—Newfoundland route is, of course, longer in total mileage, but this extra mileage, namely, about 760 miles, is appreciably less than that involved in the wholly southern route. The saving of more than 25 per cent. of the fuel required for a given power output and the corresponding reduction in

size of aircraft required, would go a long way towards providing the extra 30 to 35 m.p.h. in cruising speed which would be required to effect the longer total distance in the same time. However, consideration of this alternative route is of little practical value owing to the lack of facilities at the Azores and the bad conditions prevailing at Newfoundland during the winter.

All these considerations point with unmistakable directness to the outstanding advantages of providing sufficient range for the direct crossing from Southampton to Montreal or New York. The provision of this range presents a formidable problem to the designer, but it can be done, and it appears to me that only by doing it can a really successful Atlantic service be established. Once the design problem has been faced and solved, not only are the prospects for a fast and regular service enormously improved, but the degree of flexibility is greatly increased. The bases in Eire and Newfoundland will provide invaluable emergency landing places, while the ability to reach a point 1,000 miles or so beyond the first landfall will open up a reasonable prospect of being able to reach some other alternative base in the event of bad conditions at the regular terminal.

Even if and when the necessary range is provided for the through flight, the marine aircraft will be at a disadvantage under winter conditions. Montreal is put out of action by ice during the winter months and even New York is not immune from this difficulty. However, the period during which New York is likely to be out of action is comparatively short, and it may in the future become possible to stretch the range of the marine aircraft by the further 200 miles required to reach Baltimore which remains open throughout all but the severest winters. A shuttle service from New York or Baltimore to Montreal could be maintained with land type of aircraft.

Even the land type aircraft will have to face difficult conditions at Montreal during the winter months, chiefly on account of snow. But the general conditions at Montreal are likely to be far more favourable than those at Hatties Camp, and if it proves to be feasible to deal with the snow difficulty by one of the methods proposed, it should become possible to operate to Montreal with land type aircraft with regularity throughout the year.

I have mentioned above that no attempt has yet been made to explore the possibility of regular operations over the North Atlantic during the winter months. It is certain that very strong winds will have to be faced and it is reasonably certain that severe icing conditions will be prevalent over considerable sections of the route. It is not an inviting prospect for the personnel who will have to carry out such services, and it will only be justifiable to explore the possibilities of such winter services when, apart from the provision of really adequate safeguards against icing, a very ample margin of range has been provided. It is impossible at this stage to say what that margin must be for regular operations; a good deal will depend on the extent to which Hatties Camp and other alternative emergency bases further on can be used in emergency. If such alternative bases can be shown to offer between them a safe haven in case of exceptional conditions, it may prove to be sufficient for the through service to provide only for a continuous adverse wind of 40 m.p.h. plus the usual allowances for take-off and landing.

The purpose of this paper is to deal with the technical rather than the political aspects of Atlantic aviation, but in considering this question of the available alternative routes it is hardly possible to avoid some reference to political considerations. The direct route from Southampton to Montreal involves no political difficulties to British interests except those which may arise from agreements already made with other Governments concerned. I am not in a position to discuss such agreements or how far they tie down future services to scheduled calls at the bases which have been established. I can only say that from the technical point of view it appears to me that scheduled calls at Eire and Newfoundland for all services will be very prejudicial to the establishment of regular services between Great Britain and Canada or the United States. Whatever

may happen about this, the establishment of the bases in Eire and Newfoundland will not have been wasted effort, because such bases are an obvious necessity even where through services are concerned. On the more southerly route the most important political consideration appears to arise from the natural Portuguese desire that services operating through the Azores shall call at Lisbon. It is only necessary to mention that the effect of including a call at Lisbon is to increase the mileage for British services by this more southerly route by some 450 miles.

I have made no reference in this brief review of alternative routes to the scheme for the provision of floating islands or " seadromes " which was proposed some years ago. The object of this scheme was to split the Atlantic crossing into a number of comparatively short stages, thus enabling the crossing to be made by aircraft of normal characteristics. This scheme proved to be impracticable for financial and other reasons and it cannot be seriously considered in connection with future Atlantic services.

I trust that the remarks I have made in this section in regard to the bases in Eire, Newfoundland and the Azores will not be misinterpreted as indicating a disregard of the splendid co-operation accorded by the various governments concerned; my purpose has been merely to deal with the technical position as I see it.

Nature of Services Required.

The value of air transport must always depend on the other means of transport which exist over the route concerned. An air service to the principal cities of Australia in about ten days offers a saving of time of over four weeks, and is, therefore, obviously of great value for both passengers and mails. An air service to Central Africa saves about three weeks and this also is obviously of great value. An air service from London to Paris saves a few hours only, but even so, it is of some significance from the time saving point of view. It has, however, the additional advantage of avoiding much discomfort and it is partly for this reason that it is so popular with the travelling public.

An air service between London and Edinburgh or Dundee actually loses working time to the business man; he can travel so conveniently by train at night and do his business during the day. Air services of this kind are of little significance.

The Queen Mary and the Normandie can make the Atlantic crossing in less than five days, and in doing so they provide a very high standard of comfort for the passengers. The Queen Elizabeth will increase the frequency of these high speed steamship services. A passenger air service over the Atlantic cannot hope to offer a comparable standard of comfort, and to make up for this it must offer a very substantial saving in time. I venture to think there will be in the long run comparatively few passengers who will be prepared to sacrifice the amenities of their ocean crossing by liner unless the air service will get them across safely and reliably within 24 hours. In the case of mails, I do not see how an air service can successfully compete with the present mail, cable and telephone facilities, unless it can be cut down to an overnight service or something very closely approaching it.

But high speed is not everything. The air service must also have a high frequency if it is to succeed in competition with surface transport. My own view is that so far as mails are concerned the aim should be a daily overnight service throughout the year between London and Montreal and London and New York. The present temporary weekly service is a demonstration and a trial, and no one would suggest that such a service would meet requirements for the future. It is not desirable in this paper to enter into a discussion on the reciprocal arrangements made with the United States Government in regard to the frequency of air services. I only say that so far as mails are concerned, the service must run daily if it is to be really effective.

The requirements for a passenger service are, I venture to think, somewhat different. On the one hand, passengers demand and expect to get the highest standard of comfort which air transport can offer, and, on the other hand, they do not expect to pay for it. Air transport for passengers has in fact developed under a system of heavy subsidisation, direct or indirect, by all the principal nations, and although only a very small proportion of the travelling public can or do take advantage of the facilities provided, the system has been accepted without much complaint by the taxpayers. They feel that they get value for their money in national prestige and the general benefit to the community as a whole. But the carriage of passengers by air is vastly more costly than the carriage of mails, and the passenger is asked to pay only a relatively small proportion of the cost. The actual weight of the average passenger is about 165 lbs., but for long range travel he must be given an allowance for baggage which will bring his gross weight up to about 250 lbs. But this figure by no means represents the total weight which the aircraft must carry per passenger. When allowance is made for the provision of spacious saloons and their furnishing, decoration, ventilation, heating and sound proofing, and the elaborate equipment which must be provided for the safety and general comfort of passengers, it will be found that the total weight involved in the accommodation of each passenger amounts to a formidable figure. This figure will vary somewhat according to the size and type of aircraft, but in general it will certainly not be less than 250 lbs. per passenger. This brings the total effective weight per passenger to at least 500 lbs.

With the normal limiting weight of half an ounce per letter, it is found that an average of about 40 air mail letters go to the pound, and on this basis each passenger carried is equivalent in weight to about 20,000 letters. In the case of the present experimental Atlantic mail service the charge per $\frac{1}{2}$ oz. letter is 1s. 3d., and it will be seen that the equivalent passenger fare for the single journey should be £1,250. It is not, of course, contemplated that a fare of this order should be charged or that it could be obtained if it were charged. It is too early to predict what the ultimate passenger fare will be, but it seems unlikely that it will be more than about one-tenth of the figure mentioned. I do not suggest that the ultimate cost to the transport company will be as high as £1,250 per passenger; it will depend so much on the volume of traffic available. But in any case, the figures quoted tend to show that passenger traffic on such a service is relatively unprofitable, and it is the taxpayer who must make it worth while to the operating company. It can, of course, be argued that if air transport is to be provided in any case the aircraft can be made large enough to carry a certain number of passengers in addition to mails, and that any revenue obtainable from passenger fares will help in the general budget. This argument may be sound up to a point, but it is apt to lead to false conclusions as to the size of aircraft required. It does not break down the general principle that provision for passenger accommodation in the design of the aircraft very greatly increases the cost of long range air transport.

It appears to me that the primary purpose of subsidised air transport should be the provision of high speed mail services at rates which come within the means of the population as a whole, and that the carriage of passengers at subsidised rates should be regarded as a secondary purpose. If this principle is admitted it is hard to avoid the conclusion that in the case of Atlantic air services there is a very strong case for the segregation of passengers and mails. The mail service requires very high speed and high frequency to make it effective, and these advantages can only be achieved at reasonable cost if the aircraft is designed to be as small as possible having regard to the mail load to be carried and, of course, to the necessity of providing all necessary facilities for navigation and safety of the crew. The passenger service does not require the same high speed or the same frequency, and it is much more possible to design a large aircraft with the necessary facilities and safety for passengers if only moderate

speed is required, and to operate such aircraft on a reasonably economic basis if only moderate frequency is required.

There is another important factor which enters into this question of segregation of passengers and mails. I have pointed out above how far we are from having overcome the difficulties of bad weather conditions over the North Atlantic during the winter months, and how unsatisfactory the facilities are on the more southerly alternative route. It appears to me that for at least several years to come the standard of safety which can be assured during the winter months will not be such as to justify the carriage of passengers. It can, of course, be argued that if the standard of safety is not going to be high enough for passengers it is not going to be high enough for the crews of mail carriers, but I do not myself think this is a valid argument. The present stage of development of air transport all over the world has been reached largely through the courage and devotion to duty of the flying personnel, and in my opinion we are far from having reached the stage when the flying personnel need no longer be called upon to face risks greater than those to which passengers can legitimately be subjected. I do not think that passengers ought to be carried over the North Atlantic during the winter months until the hazards have been thoroughly explored by the flying personnel. The record of safety over established routes is not yet such as to justify the carriage of passengers over a new route under conditions known to be far more difficult than anything previously tackled.

This view may not be generally accepted, but if it is accepted, it strongly supports the case for segregation of passengers and mails, at any rate during the next few years. If passenger services are to be suspended during the winter months, surely it is better that the mail services which continue should be based on the most suitable and economic type of aircraft for the purpose. In this connection I would mention that maximum possible speed, apart from its advantage from the traffic point of view, will be a great asset to the flying personnel to whose lot will fall the duty of exploring the conditions over the North Atlantic during the winter months. High speed will not only minimise the effect of strong adverse winds, but will also reduce the physical strain on the flying personnel.

Before concluding this section of the paper it is necessary to refer briefly to the question whether British Atlantic air mail services will remain on the basis of a surcharge or come into the " all-up " mail scheme which has been applied to services to other parts of the Empire. This is a question of policy which, so far as I know, has not yet been decided, but it so materially affects the design of aircraft required that it is hardly possible to ignore it. I believe that the total volume of first class mail matter carried from Great Britain to Canada and the United States amounts to approximately 800 tons per annum, and that the corresponding volume in the opposite direction is just over 650 tons. If Canada only is considered, the total loads are approximately 325 tons per annum from Great Britain to Canada and 215 tons per annum from Canada to Great Britain. On the basis of a daily service throughout the year capacity would thus have to be provided for approximately one ton to cover an all-up mail scheme between Great Britain and Canada, and if the British proportion of mail for the United States were to be carried in the same aircraft the capacity would probably have to be doubled.

On the other hand, the subsidisation required for such a service would be very high and on this and other grounds there is a fairly strong case for excluding North Atlantic services from the Empire mail scheme. The existing communications between Great Britain and Canada are far quicker than were the communications between Great Britain and Australia or Central Africa before the introduction of the Empire air mail scheme. The Atlantic air mail service offers in effect the prospect of being able to reduce the time to substantially that taken by night letter telegram, while retaining the advantages of a mail system. It appears reasonable that the users of such a mail service should be called upon to pay a moderate surcharge as a contribution towards its cost.

On the basis of a surcharge of 1s. per ½ oz. letter, the facilities offered would be better and very much cheaper than those offered by night letter telegram, and it seems reasonable to suppose that good use would be made of the service at this surcharge when once it had been proved to be regular and reliable. The service might well attract between 5 and 10 per cent. of the present first class mail matter, and on this basis provision would have to be made for a total capacity of about one and a half tons a week in each direction. With a daily service throughout the year the capacity required would be about 500 lbs. per service, and an aircraft designed to carry 1,000 lbs. of pay-load would provide a good margin for future expansion and for carrying express freight—a type of traffic which appears likely to be available in considerable quantities on this route.

500 lbs. of mail per trip may seem a small load in relation to all the elaboration of an Atlantic service, but it appears to be all that is likely to be available on a reasonably commercial basis. It does not seem such a small amount when expressed as 20,000 letters or £1,000 of revenue.

On the basis of this moderate load, it is already possible to design a reasonably economic aircraft to meet the exacting requirements as to range and speed.

Finally, it is necessary, before passing on to the problems of design, to define more precisely the requirements in regard to performance. I have expressed the view that nothing short of through services between Southampton and Montreal or Southampton and New York will prove to be really worth while, and this defines the range required as 3,200 or 3,400 miles against the prevailing wind. I have suggested that an allowance of 40 m.p.h. for the continuous westerly wind may prove to be sufficient, provided there is a reasonable choice of alternative bases on the other side. As regards the question of speed I have stated in general terms that the speed must be the maximum possible and that in my view the service must be as nearly as possible an overnight service, but it is now necessary to set down some definite idea as to what the cruising speed must be.

There are two factors of fundamental importance, one of which is favourable and one unfavourable in each direction. One of these factors is the prevailing wind and the other the difference in time of about five hours, due to the difference in longitude between the terminals. The latter factor is, of course, favourable to the westerly crossing and unfavourable to the easterly, and somewhat surprisingly this factor is the more important of the two. The effect of these two factors can be seen more clearly by considering specific cases such as those set out in the following table which relates to the Southampton—New York stage of 3,400 miles. In the case of the westerly crossing the average adverse wind is assumed to be 40 m.p.h. while in the case of the easterly crossing the average favourable wind is assumed to be 20 m.p.h., the difference providing a margin on which reasonably reliable schedules could be based.

Stage.	Cruising Speed.	Net Cruising Speed.	Actual Time (hours).	Effective Time (hours.).
Southampton—New York ...	150	110	31.0	26.0
	156	116	29.3	24.3
	200	160	21.3	16.3
	250	210	16.2	11.2
	300	260	13.1	8.1
	350	310	11.0	6.0
New York—Southampton ...	150	170	20.0	25.0
	156	176	19.3	24.3
	200	220	15.5	20.5
	250	270	12.6	17.6
	300	320	10.6	15.6
	350	370	9.2	14.2

It will be seen that the advantage of approximate equality of scheduled times for the easterly and westerly crossings can only be obtained at very low speeds. On the basis of the assumptions made actual equality occurs at a cruising speed of 156 m.p.h. At cruising speeds below this the westerly crossing is effectively longer than the easterly, and above this speed the reverse is the case. It appears to me, however, that so far as mail services are concerned, an effective time of the order of 24 hours is far too long, and that it is necessary to consider very much higher speeds with the attendant disadvantage of a wide disparity between the scheduled effective times for the easterly and westerly crossings. The criterion for minimum cruising speed then becomes the maximum effective time which can be allocated for the easterly service.

If the service is to be effectively an overnight service, letters posted in New York towards the close of the business day must be delivered in London in time for them to be dealt with and replied to on the following day. Reference to the table will show that for a cruising speed of 300 m.p.h. the effective time taken is 15.6 hours. If an allowance of two hours at each end is made for collection or delivery and transit between the capital and the airport, this would mean that a letter posted in New York at 5.0 p.m. could be delivered in London at approximately 12.30 p.m. the following day. In the other direction the effective time is only 8.1 hours, so that a letter posted in London up to 8 p.m. could be delivered in New York at approximately 8 a.m. the following morning. Thus the recipient of a letter in London would have a long afternoon in which to prepare his reply for despatch the same day.

It will be seen that even with a cruising speed as high as 350 m.p.h. it is still not possible to achieve an early morning delivery in London, and unfortunately it must be admitted that a cruising speed of 350 m.p.h. is outside the region of practicability in the present stage of development.

It appears to me, therefore, that the aim for a mail service must be a cruising speed of 300 m.p.h. or something very little short of this figure.

Where passengers are concerned there is not the same urgency, although the time may come when even passengers will expect to make the return journey in two consecutive nights, leaving the working day for the conduct of business. But such passengers will require a relatively high standard of comfort on the journey and they can only attain this if large aircraft are provided. In the present stage of development cruising speeds of the order of 300 m.p.h. for large passenger carrying aircraft are not feasible and the cruising speed provided must be a compromise between urgency and comfort. Actual time in the air is perhaps a more important criterion than effective time where passengers are concerned. A cruising speed of 200 m.p.h. gives an actual time of 21.3 hours in the air on the westerly crossing, and it may be that this is as much as most passengers will care to stand. If the cruising speed is raised to 250 m.p.h. the time in the air is reduced to 16.2 hours, but the attainment of this speed in association with spaciousness and comfort for passengers presents a formidable problem to the designer. The lower speed and the higher standard of comfort may prove to be the more attractive proposition to the majority of passengers.

The Design Problem.

The range and speed requirements outlined above cannot be met by aircraft of normal present day characteristics. They can only be met by employing very much higher wing loadings than those which can be regarded as safe and practicable for normal short and moderate range operations.

The present-day standard, with the relatively high lift wings generally employed, may be taken to be from about 25 to 30 lbs. per sq. ft. at the start of the flight. If the full requirements as to cruising speed and range are to be met, it appears necessary to increase the initial wing loading to the order of 50 lbs. per sq. ft. or a little over. Theoretically it would be advantageous to increase the initial wing

loading to a higher figure still, thus enabling the majority of the flight to be made under conditions more nearly approaching the best lift/drag ratio, but the determining factor is the landing condition, and this in practice precludes the use of initial wing loadings much in excess of 50 lbs. per sq. ft. for a commercial aircraft unless an even longer range is required. The wing loading on completion of the flight must be brought down to the safe limit which, allowing for the use of devices for increasing the maximum lift coefficient at landing, must be fixed at a figure not far exceeding 30 lbs. per sq. ft. Having regard to the fact that the payload of a commercial aircraft is not disposable, it will be found difficult in practice to meet this condition if the initial wing loading is raised to the optimum figure.

But even when the initial wing loading is confined to approximately 50 lbs. per sq. ft. it is extremely difficult to provide the aircraft with a satisfactory take-off performance. So far as I know no commercial aircraft has yet taken the air with so high a wing loading, and it appears to me inevitable that the employment of such wing loadings with aircraft intended for direct take-off must introduce seriously increased risks. These increased risks do not arise only from the length of run required for take-off but also from the high speed which must be reached while in contact with the ground or water, the low initial rate of climb, the prolonged use of full power involving heavy strain on the engines, and the inability to effect a safe landing in the event of trouble until sufficient height has been reached to permit of jettisoning the fuel load.

Raising the wing loading at the sacrifice of take-off performance is the easy way of increasing the range and cruising speed of long range aircraft, but it remains to be seen how far it can be carried in practice. Up to the present time it has not been carried nearly far enough to produce a direct take-off aircraft complying with the performance requirements indicated above. The highest loaded British commercial aircraft so far employed with direct take-off is, I think, the Short S.30 flying boat, which for a take-off weight of 50,500 lbs. has a wing loading of 33.7 lbs. per sq. ft. This is in association with a power loading at take-off of approximately 13.75 lbs. per horse power. The take-off of this aircraft under these conditions is reasonably satisfactory, the time required being approximately 40 secs., which is well within the somewhat anomalous limit of 60 secs. laid down by the airworthiness regulations. But it must be admitted that even with this comparatively moderate standard of wing loading good surface conditions are required. The S.30 flying boat has been developed from that most successful type the Short Empire flying boat, but its performance in range and speed naturally fall far short of the severe requirements set out above. The length and time of run for take-off and the risks involved will be very different if and when wing loading is increased to the order of 50 lbs. per sq. ft.

The Short G. Class flying boat, which has started its preliminary trials, will carry the matter of initial wing loading slightly, but only slightly, further. This aircraft is designed for higher cruising speed, and by virtue of its much larger size than that of the S.30 it will have a better range and load capacity, but even so it will fall a long way short of the desired range and cruising speed.

I am not able to quote figures for the Boeing 314 flying boat which has been used by Pan American Airways during this year's Atlantic services, but it appears from the voyage records that its cruising speed falls a very long way short of the standard I have suggested as necessary, and its take-off performance appears to approach the limit for safe operation under the conditions prevailing at the Southampton base.

Up to the present time no British commercial land type aircraft employing a wing loading exceeding about 30 lbs. per sq. ft. has been put into service. Certain types with considerably higher wing loadings are under design and construction, but I am not in a position to quote the anticipated performance figures for these types.

It is clear, however, that the achievement of the suggested standard of performance with direct take-off will present very great difficulty, and will inevitably involve comparatively large size. It appears to me that a land type aircraft designed as a mail carrier only and with a capacity for the 1,000 lb. load mentioned above must run to a total weight of between 60,000 lb. and 70,000 lb. if it is to meet the performance requirements. In the case of a marine type aircraft it seems very doubtful whether the desired cruising speed can be approached at the present stage of development, but it should be possible to meet the range and load requirements at an appreciably lower speed for a total loaded weight of between 70,000 lb. and 80,000 lb.

If in the case of either the land or the marine type provision is to be made for carrying passengers with a reasonable standard of comfort, the total weights involved must go up appreciably above the figures mentioned. As I have indicated above my view is that the establishment of an all-the-year round mail service is the matter of primary importance, and I do not propose, therefore, to go into any detail in this paper in connection with passenger carrying aircraft.

One important conclusion, however, appears to me to arise from the above remarks on the size of aircraft involved, namely, that these large sizes of aircraft are necessary if passengers are to be carried, but are uneconomic in relation to the comparatively small mail load which can be expected to be available on the basis of a surcharge service. It will, however, be easier to judge of this when the possibilities of assisted take-off have been considered.

There is one further important point in connection with the operation of very heavily loaded aircraft with direct take-off. In the case of the marine type a long stretch of well protected water is essential, and in spite of the fact that we live in a maritime country we do not seem able to produce a base meeting the requirements for such aircraft. Certain it is that Southampton, the selected home base for Empire and Atlantic services, does not provide the necessary facilities. Even if the advantages of a through service are sacrificed and the long range start is made at Foynes it appears to me doubtful whether the degree of protection is sufficient to permit of the regular and safe operation of very heavily loaded flying boats during the winter months. As the size of flying boat increases, however, the surface conditions will tend to become less important.

In the case of heavily loaded land type aircraft with direct take-off, very large aerodromes with specially prepared runways must be provided. Such aerodromes have been in course of development at Rynanna and Hatties Camp, but I do not know of the development of any such aerodrome within easy reach of London.

It should be mentioned that whether marine or land type aircraft are employed it is essential that the start be made at night during the winter months if the full advantages of a mail service are to be realised. This leads to the necessity of providing exceptional facilities if a service with direct take-off is to be operated with a reasonable degree of safety and regularity. The mere improvisation of airport facilities if and when the aircraft have been produced will not enable such a service to run.

In summary it can be said that the major difficulties associated with the design of long range aircraft centre round the problem of take-off and initial climb. It is mainly due to the take-off difficulty that large size is essential even where a comparatively small load of mail only has to be carried. This large size not only increases the cost of operation but involves other difficulties which have yet to be solved. As the size increases control by direct physical effort must become increasingly ineffective, and when a certain limit is exceeded it is inevitable that servo controls must be provided. But such controls must have absolute reliability, and, having regard to the limitations as to weight, it may be years before such reliability can be achieved. Moreover, increase in size, particularly in the case of land type aircraft, materially increases the difficulties of handling, and the feasible limit of size may prove to be considerably smaller in the case of land type aircraft

than in the case of flying boats. The largest commercial land type aircraft so far developed is, I believe, the Douglas D.C.4, which has a total weight of about 65,000 lbs., and it is perhaps significant that this type does not appear to have been widely adopted.

In an earlier section of this paper I have suggested that the balance of argument is in favour of the land type aircraft so far as route conditions are concerned, but in relation to the problem of direct take-off the advantage appears to be slightly in favour of the flying boat. It may be that in the end the large flying boat will establish itself as the accepted type for passenger services, while the land type, with its advantage in speed, will be used for the mail services. There is, in my view, no substantial difference between the two classes as regards safety while making the ocean crossing. Even the largest flying boat is unlikely to be able to keep afloat after a forced landing in average conditions, and safety can only be achieved by eliminating forced landings. It goes without saying that the aircraft employed must be multi-engined aircraft and that all possible precautions must be taken against engine failure, but apart from these precautions the greatest safeguard against forced landing over the Atlantic is the provision of a very ample margin of range and sufficient performance to meet all conditions.

The Assisted Take-off.

For years past it has been recognised that the take-off problem is the dominating difficulty controlling the design and operation of long range aircraft. To overcome this difficulty three different methods of assisting the take-off have been developed, namely the catapult, the composite aircraft and refuelling in flight.

(i) The Catapult.

The catapult has been employed as a means of launching aircraft from the earliest days of flying; it was used successfully by the Wright Brothers in their preparatory experiments with gliders. After the aeroplane had developed to a stage where it could take-off comfortably under its own power, the catapult dropped out and did not reappear until it became necessary to launch aircraft from ships. The catapult then provided the obvious solution to the problem of getting the aircraft into the air when practically no run was available. The catapult came into general use for this purpose from the time of the great war, and continues to provide the only satisfactory solution of this problem. It was not until after the development of the composite aircraft had started in 1932 that the use of the catapult was proposed as a means of assisting the take-off of a very heavily loaded long range aircraft. Since then there has been a great deal of talk about the potentialities of the catapult for this purpose, but so far as British practice is concerned the stage of practical trial has never been reached.

The catapult has, however, been used with considerable success by the Germans, particularly in connection with South Atlantic services. The main purpose which the catapult has served has been to enable the flying boats employed to be refuelled in mid-ocean. The catapult has been mounted on a ship which has formed the refuelling base. The ship has provided a sufficient measure of protection to enable the flying boat to land in the open ocean. The flying boat has then been lifted on board by means of a crane, refuelled, mounted on the catapult and launched for the continuation of its flight. This operation has been repeated successfully a very large number of times in the South Atlantic where conditions have proved to be good enough to permit of the landing of the flying boat at light load. The distances involved on the South Atlantic service with refuelling stops were not, however, long enough to necessitate the employment of very high wing loadings, and it was the fact of the take-off having to be done in the open ocean rather than under extreme conditions of loading which necessitated the use of the catapult. More recently, however, an experimental service over the North Atlantic via the Azores—Bermuda route was conducted on similar lines.

In this case the depot ships were stationed off the Azores and Bermuda and the experiment approached more nearly to a test of the catapult for the launching of a heavily loaded aircraft. Several successful flights were made in this way, but the attempt to develop a regular service on these lines has not been pursued. It has been stated by a German authority on this subject that the catapult method of launching has been found to be unsuitable where large heavily loaded aircraft are concerned.

Apart from the discontinuation of this experimental service it is apparent that this method of launching marine aircraft must be inordinately expensive. Each of the depot ships must be of considerable size, since they have to carry the crane, the catapult and a good deal of ancillary equipment, and in addition they must be seaworthy for the purpose under ocean conditions. Each ship necessitates a considerable crew, and both capital and operational costs are inevitably high in relation to the service performed. Even if the operation does not have to be performed in the open ocean a ship or barge of large size is required to carry the crane and catapult, the length of which will depend on the wing loading employed and the acceleration permitted. In military practice accelerations up to $2\frac{1}{2}$ g. or even more can be employed, but this figure would involve difficulties in commercial practice. If passengers were concerned it would probably not be feasible to use a higher acceleration than 1 g., and even that might cause considerable resentment. The length of catapult required would be, say, 300 to 400 ft., according to the wing loading and minimum launching speed permitted.

The employment of the catapult for the launching of a land type aircraft is open to similar, if not quite so serious, objections in regard to cost, and difficulties in providing satisfactorily for orientation into the wind and general mobility are also involved.

But there is an objection to the catapult more serious even than the objection as to cost, namely, that it only succeeds in getting the aircraft into the air at ground or sea level and (if the dimensions of the catapult are to be kept within reasonable limits) at a speed not far in excess of the stalling speed. It does not help the initial climb and leaves the aircraft in a precarious plight if loss of power or other cause should necessitate an early landing. Safe jettisoning of fuel is a comparatively lengthy process, and the pilot would not have time to make use of this means of reducing load if trouble occurred at an early stage. This is a fundamental objection which prevents the catapult from providing a complete solution to the problem.

Proposals have been made for various forms of catapult and also for accelerators which come into the same general category, but all are subject to the same disabilities in regard to cost, immobility and failure to provide a complete solution to the problem of getting very heavily loaded aircraft safely into the air. It is for these reasons that after all these years of development of the catapult so little has been done to apply it in practice for the launching of a heavily loaded long range commercial aircraft. It appears to me that even if this form of assisted take-off is developed further in the future, it will serve only for the launching of aircraft of small to moderate size, because the lifting of a very large aircraft, whether of marine or land type, into position on the catapult will remain a permanent practical difficulty.

(ii) The Composite Aircraft.

I do not propose to describe in detail the features or principles of the composite aircraft, as I think these are already fairly well known. The prototype composite aircraft, which was of marine type, was designed and constructed by Short Brothers and completed early in 1938. The first separation flight took place in February 1938, and there followed an exhaustive series of makers' and official trials, including a number of separations at light and full loads. At the time when the design of this particular composite aircraft was started the general

standard of wing loadings employed was very much lower than it is to-day, and in fixing the normal full load wing loading of the upper component, Mercury, at 34 lbs. per sq. ft., a big step up was made. A much higher wing loading could have been decided upon, but it was considered advisable to test out the principles of the composite aircraft under moderate conditions in the first place. Apart from the advantage to be gained by high wing loading, the composite aircraft offered several important secondary advantages, including that of providing flotation only for the comparatively lightly loaded landing condition and the ability to employ fixed pitch wooden propellers without incurring any penalty in regard to take-off. By virtue of these advantages Mercury was able to offer ample range for the North Atlantic crossing at a cruising speed well in advance of the existing standard for marine type aircraft and when carrying a net payload of 1,000 lb. of mail.

In spite of the complete departure from previous practice the trials of the composite aircraft were completed without a hitch of any sort and the aircraft was immediately set to demonstrate its ability to perform the Atlantic flight. This it did on July 20th-21st, 1938. The start was made from Foynes with Mercury loaded to her full normal weight of 20,800 lbs. The weight of the lower component, Maia, as part of the composite aircraft was 27,800 lbs., so that the total weight of the composite aircraft was 48,600 lbs. At this weight the take-off was effected comfortably in 17.5 secs. and after a correspondingly short run. After a normal separation Mercury proceeded on her course and reached Newfoundland some 13 hrs. 20 mins. later. In spite of the 25 m.p.h. average headwind encountered this was the fastest East to West crossing so far made. It remains the fastest East to West crossing by a marine type aircraft. The range provided was sufficient to enable Mercury to reach her scheduled destination Montreal non-stop. Strong headwinds of from 40 to 50 m.p.h. were encountered between Newfoundland and Montreal and the total distance of 2,860 miles was made in 20 hrs. 20 mins. This was not only the fastest East to West crossing, but the first Atlantic crossing on which a commercial load was carried. Incidentally, I believe it was the first crossing made by an airworthy aircraft, i.e., an aircraft loaded within the limits prescribed by its certificate of airworthiness.

After depositing some of the load at Montreal Mercury proceeded on to New York as a normal aircraft, and two days later started her return flight via Montreal, Botwood, Horta, and Lisbon.

Preparations were then made for a longer range flight by Mercury, partly to demonstrate the efficiency gained by this method of assisted take-off, and partly to give an opportunity of proving that the principle could be applied at once to very much higher wing loadings than the 34 lbs. per sq. ft. for which Mercury was designed. For this purpose Mercury was loaded up to a total weight of 27,500 lbs. representing an increase of no less than 6,700 lbs. above the total weight for the Atlantic crossing. Under these conditions the disposable load represented 62.5 per cent. and the tare weight only 37.5 per cent. of the total weight. The start of this flight was made from this City of Dundee, and, in spite of the bad conditions which the River Tay managed to produce, the take-off of the composite aircraft was effected in 23 secs. It was a matter of great regret to those on board that the presence of large masses of cumulus cloud prevented the separation being seen by the citizens of Dundee who had displayed such a lively and kindly interest in this flight. The separation was made at about 5,000 ft. and, in spite of the heavy overload carried by Mercury, was entirely satisfactory. By increasing the speed of the composite aircraft appropriately, the separating force had been increased in proportion to the increased weight of Mercury, and the rate of vertical separation obtained was at least as great as for any of the previous separations at lighter loads.

The particular significance of this separation of the composite aircraft lay in the fact that Mercury was loaded at separation to 45 lbs. per sq. ft. of wing area

and 20 lbs. per rated h.p. of the Napier Rapier engines. No aircraft had ever previously flown at a combination of wing and power loadings approaching these figures, yet the launching was effected with complete safety and at a speed approximating to the cruising speed of Mercury, which flew off under perfect control on the start of its long flight. The success of this separation was such as to leave no doubt that the method can be applied immediately to the launching of aircraft of even higher wing loadings. I have mentioned the combination of high wing and power loadings at this separation and this is an important point, because in future designs of upper component to meet the full range and speed requirements for the Atlantic, the power loading must necessarily be very much lower in order to achieve the desired speed. Thus, though the wing loading may be increased from 45 to, say, 52 lbs. per sq. ft., the accompanying reduction in power loading from 20 to about 10 lbs. per horse power will give the upper component the higher performance desired and will ensure even better flying qualities after the separation.

Captain Bennett set Mercury straight on her course to South Africa, and in spite of ice-forming conditions over England and adverse winds over the route, landed safely at the mouth of the Orange River some 42 hours later. The non-stop distance covered was approximately 6,000 miles which constituted a new world's record for marine aircraft by a margin of nearly 800 miles. The flight thus provided, in addition to the test of separation at high wing loading, a demonstration of the practical value of this high loading for long range work. If for this flight the fuel and oil had been limited to that required for the through Atlantic range of 3,400 miles against a 40 m.p.h. headwind a payload of about 4,000 lbs. could have been carried. This figure represents about 3 lbs. per rated h.p. of the engines, which is appreciably better than the figure for most modern short-haul air liners.

After returning from South Africa by easy stages under her own power Mercury was put into service by Imperial Airways in connection with the Christmas Empire mail programme. For this service the total weight at separation was limited to the normal maximum of 20,800 lbs., but even so Mercury was able to make the distance of approximately 2,400 miles between Southampton and Alexandria non-stop when carrying a load of one ton of mails. These flights were made alternatively by day and by night in mid-winter conditions, and they afforded a demonstration of the general serviceability of the aircraft and the method of launching.

These flights completed the series of trials and demonstrations of the prototype composite aircraft and it was satisfactory to all concerned that the whole programme was carried through from start to finish without a set-back of any sort. The operation of mounting was carried out under varying conditions and at various places without difficulty, and no equipment other than standard dock equipment was employed. The piloting of this prototype composite aircraft was undertaken by a number of successive crews. The initial trials were made by Mr. Lankester Parker, Chief Test Pilot of Short Brothers, and his Assistant, Mr. Piper. Then followed the official trials which were conducted by Royal Air Force personnel, and later when the aircraft was taken over by Imperial Airways the further trials and demonstrations were made by Captain Wilcockson and Captain Bennett. None of the crews experienced any difficulty in handling the aircraft or in the process of separation, and it was gratifying to find that the pilots who gained practical experience with the functioning of the composite aircraft became enthusiastic supporters of the principle.

As soon as the principle and practicability of the composite aircraft had been clearly established a new design of upper component to meet substantially the exacting performance requirements set out above for an Atlantic mail service was prepared by Short Brothers for Imperial Airways. It was decided that this new design should be a land type version in order to take advantage of the higher

performance offered, and it was proposed to utilise certain units of the Armstrong Whitworth Ensign fleet, with slight modifications, as lower components. The stage of issuing instructions to proceed with construction had been reached when the Air Ministry intimated that they did not desire the composite aircraft to be further developed for Atlantic services for the reason that it did not make provision for carrying passengers. Since then further progress with this design of composite aircraft, which offers a performance far in excess of that offered by any previous or subsequent proposal of which I have knowledge, has been suspended.

An article which appeared recently in a leading journal contained the following reference:—

> "The principle of the composite machine has been proved by the successful flights of the seaplane Mercury, and it is one of the major mysteries of British civil aviation that more use has not been made of this system, especially when the need for separating mails and passengers is coming to be accepted."

The decision to which I have referred certainly was and remains a mystery to all those who have taken an active part in the development of the composite aircraft. It was known from the first that in its commercial application the principle would lead essentially to a mail carrier. It does not lend itself to the launching of very large aircraft, because the upper component must necessarily be considerably smaller than the lower. It was with clear knowledge of this that the Air Ministry encouraged and financed the development of the prototype composite aircraft. This development entailed not only the expenditure of a large sum of public money, but also the expenditure of a vast amount of effort not only by those who contributed towards the design and construction of the composite aircraft, but also by those who so successfully demonstrated it. If the results obtained had been in any way unsatisfactory, or if any unforeseen practical difficulty had been experienced, the decision would be understandable, but when that decision follows immediately upon trials and demonstrations which achieved success beyond the highest hopes, it is a little difficult to understand. Especially so when the case for segregation of passengers and mails seems now to be so much stronger than it was at the time when the original decision to proceed with the development of the composite aircraft was taken.

It must be admitted that the case for the composite aircraft in commercial aviation stands or falls on the question of segregation or non-segregation of passengers and mails. There is, of course, no absolute limit to the size of the upper component or the composite aircraft as a whole, but practical considerations make it desirable to limit the size of the upper component to a total weight of from 30,000 lbs. to 35,000 lbs. in the present stage of development. Generally speaking, the upper component will have a total weight up to about 65 per cent. of the total weight of the lower component when the latter is fully loaded as a normal separate aircraft. It is thus in effect the size of lower component required that determines the practical limit for the size and weight of the upper component. Owing to the very high wing loading permitted by this method of assisted take-off, the size of the upper component will be relatively small in relation to its weight. Thus, even though an upper component of 30,000 lbs. to 35,000 lbs. total weight can carry a substantial payload for the Atlantic range, it offers only limited cubic capacity in relation to this payload. Such an upper component could readily offer sleeping accommodation for a certain number of passengers, but the spaciousness would not be up to the standard required for regular passenger services over the Atlantic. What it comes to is that the composite aircraft could offer reasonably good emergency accommodation for a few passengers, but it is not a suitable type to form the main equipment for Atlantic passenger services of the future.

The surprise which I have expressed at the suspension of the development of the composite aircraft for Atlantic services is thus not based on any idea that the composite aircraft is suitable for all Atlantic services, but on the demonstrated

fact that it is particularly suitable for the high speed mail services which, in my view, should be regarded as the first objective and which appear to be the only services which can be established on an all-the-year-round basis for some time to come.

The prototype composite aircraft was designed essentially to demonstrate the principle and there is, of course, no suggestion that the performance of this particular composite aircraft is sufficient to meet the severe requirements which I have set out above. Nevertheless, the performance of Mercury on its 1938 Atlantic flight will be seen to compare favourably with that of the much larger S.30 flying boats which have been doing the experimental service this year. Provided with only about two-fifths of the power it carried the same payload as the S.30's have carried; it cruised at 30 m.p.h. higher speed and made the through flight from Foynes to Montreal (2,860 miles) against the Foynes-Botwood stage (2,000 miles) of the S.30's. The cost involved may be taken as roughly proportional to the power employed.

But the successor to Mercury, designed as it should be as a land plane, can certainly achieve a very much higher performance, and can in fact meet the requirements which I have set out above as necessary for an effective Atlantic mail service. It can do this at relatively low cost, and I believe that I am right in saying that, irrespective of cost, it is the only feasible type of aircraft which can achieve this performance in the present state of the art.

The essential advantages of the composite aircraft scheme of assisted take-off as applied to commercial aviation may be summarised as follows:—

(1) It eliminates the take-off problem for heavily loaded aircraft. It provides for a quick take-off and a short run and thus dispenses with the necessity for special airports.

(2) It launches the heavily loaded aircraft at a safe height and at a safe speed far above the stalling speed. By doing this it eliminates the risk of crashing due to engine or other trouble at or soon after the take-off.

(3) It relieves the engines of the long range aircraft of the heavy strain associated with direct take-off and initial climb, and thus makes for engine reliability.

(4) It enables the smallest and most economic size of aircraft to be employed and is thus particularly well adapted for long range mail services.

(5) It offers scope for the effective use of compression ignition engines. The one serious drawback to these engines in normal practice is the lack of excess power for take-off, but this does not matter in the case of the composite aircraft.

(6) It is particularly suitable for launching an aircraft designed for stratosphere or high altitude flying.

(7) It offers a high degree of mobility; the auxiliary aircraft (the lower component) can fly from base to base and a standard dock or builder's crane can be used for the operation of mounting.

(8) Obsolescent aircraft of moderately large size can be adapted with comparatively little modification to form suitable lower components.

(9) The capital and operating costs of the auxiliary aircraft and equipment are comparatively small in relation to the great reduction in capital and operating costs effected.

(10) It has demonstrated its suitability for operation in varying weather conditions and is in principle suitable for night operations.

(11) It is the only method of assisted take-off which has been successfully demonstrated for the launching of a very heavily loaded aircraft.

(iii) Refuelling in Flight.

Refuelling in flight was introduced many years ago in America and was first applied for the purpose of keeping an aircraft in the air for long periods. Almost

incredible records of this kind were set up, one aircraft and its crew having remained in the air continuously for a period of about three weeks during a fine spell of weather. But the object gained was not apparent and enthusiasm soon died down. Refuelling in flight has never since been applied to practical purposes in American aviation.

Some years ago refuelling in flight was taken up in this country, at first with the more or less similar object of increasing the time during which an aircraft could remain in the air. It was subsequently realised that it might be used to overcome the take-off problem by allowing the aircraft to take-off light and then adding a considerable part of the fuel load during flight, and this application of refuelling in flight has since received several years of intensive development in this country.

One of the main problems involved was, of course, to provide a satisfactory and reliable method of making contact and then passing the hose between the tanker aircraft and the air liner. Several methods of effecting this have been proposed, one by Squadron Leader Atcherley which has been developed by the Royal Aircraft Establishment, Farnborough, and various alternative methods by Sir Alan Cobham and his Company, Flight Refuelling Ltd. It is beyond the scope of this paper to go into the details of these various methods or the ways in which various troubles have been overcome. It is obvious that any system of refuelling in flight must involve a serious fire risk unless meticulous care is taken to prevent the spilling or discharge of fuel in the region of the air liner during or on completion of the process of refuelling. This fire risk is associated with the possibility of static discharge about which present knowledge is somewhat deficient. There are many other mechanical problems involved, and Sir Alan Cobham and his Company are to be congratulated on the determination with which they have tackled these problems and gradually evolved a refuelling scheme suitable for trial in actual service.

A demonstration of refuelling the long range Empire boat Cambria was made successfully in January, 1938, and it was then decided to employ refuelling in flight in connection with the experimental North Atlantic service with the S.30 flying boats Cabot and Caribou this summer.

There were, however, many difficulties to be overcome and unfortunately there were delays also in the completion of the aircraft, so that it was not until August that a start could be made. The S.30 boat is stressed for a maximum total weight of 53,000 lbs., and it was originally intended that its take-off weight should be limited to about 46,000 lbs. and that the balance should be taken on board by refuelling in flight to the extent of about 950 gallons. It was found later that the take-off of the S.30 boat with constant speed propellers was so satisfactory that the permissible take-off weight could be considerably increased and, as I have mentioned earlier, this weight has been fixed at 50,500 lbs. at which a take-off in about 40 secs. is achieved. Actually, when refuelling in flight is to be employed, the weight at take-off is usually limited to about 47,000 lbs. to 48,000 lbs., the balance of 5,000 lbs. or 6,000 lbs. being supplied by the tanker.

For the purpose of this experimental Atlantic service the tanker employed was the large Harrow bomber with the necessary modifications, and one of these aircraft was sent to Foynes and two to Hatties Camp, Newfoundland. It is not actually necessary for the S.30 boat to be refuelled in the air for the easterly crossing, because its range with the direct take-off gives a sufficient margin for the crossing in this direction. It was decided, however, to send two tanker aircraft out to Hatties Camp in order that a fuller demonstration of refuelling in flight could be made.

The process of refuelling in flight was successfully carried out for the first westward flight, but weather conditions between Hatties Camp and Botwood prevented it from being employed for the first eastward flight. It was, however, again successfully employed for both flights of the second service.

The conclusions which can be reached from these demonstrations are that for an aircraft of the size and wing loading of the S.30 boat the mechanical difficulties of refuelling in flight can be successfully overcome, and that the process can be regularly carried out in suitable weather conditions during daylight.

Unfortunately this experimental service has not provided an opportunity of testing whether refuelling in flight can be successfully applied to an aircraft of very high wing loading. With a total loaded weight of 53,000 lbs. after refuelling, the S.30 boat has a wing loading of just over 35 lbs. per sq. ft. and it seems that it will be necessary to raise the wing loading to the order of 50 lbs. per sq. ft. if the full performance requirements for the Atlantic are to be met. It does not immediately follow that what can be done at 35 lbs. per sq. ft. can be done at the higher loading. As the stalling speed of the air liner increases so must the minimum speed at which the operation can be done, and so must the drag of the hose and the loads imposed on the aircraft. The increase in wing loading suggested causes an increase of 20 per cent. in the stalling speed, and to ensure adequate control at the higher loading it may be necessary to fly at a speed giving a proportionately greater margin over the stalling speed. I do not suggest that refuelling in flight up to a wing loading of 50 lbs. per sq. ft. is impossible, but that considerable further development work may be required before it can be assumed to be practicable. Moreover, the amount of fuel which will require to be transferred for the higher wing loading will be very much greater than the comparatively small amount transferred to the S.30 boat; this means a longer period of formation flying and an increase in the operational difficulties under unfavourable weather conditions.

With the S.30 flying boat capable of taking off satisfactorily under protected conditions at a weight of 50,500 lbs. the effective increase due to refuelling in flight is only 2,500 lbs., against which must be debited the weight of the apparatus carried. It could not reasonably be argued that the cost and complication of any system of assisted take-off would be justified by so small an effective increase in weight. It would be far more profitable to increase the size and power of the aircraft to the comparatively small extent necessary to carry this extra weight. Alternatively, a quite reasonable direct take-off could be made with the S.30 boat loaded to its limiting weight of 53,000 lbs. In this connection it may be mentioned that the conditions of loading of the S.30 boat at 53,000 lbs. are incomparably less severe than those of Mercury at the start of the long range flight. The total weight of the S.30 would have to be increased to 67,500 lbs. to reach the same wing loading as that of Mercury, and even at this weight the power loading of the S.30 would be lower than that of Mercury, but I venture to think that refuelling of the S.30 boat in flight up to this weight would be impracticable.

It appears to me that any system of assisted take-off must carry the wing loading to an extreme figure if it is to justify itself for Atlantic services, and I do not think it can yet be assumed that refuelling in flight can be so applied. It may be, however, that further development work will show that refuelling in flight can effect a sufficient increase above the practical limit for direct take-off to justify its employment for the larger sizes of aircraft. I do not think it could be applied effectively to the smaller sizes owing to the weight and capacity required for the apparatus, the additional crew required and the relatively greater loads imposed on the small aircraft during the process.

But apart from these technical considerations I cannot help thinking that where Atlantic services are concerned, the operational difficulty will prove to be an almost overwhelming objection to refuelling in flight. Under winter conditions the occasions when it will be impossible to make and maintain contact even during daylight seem likely to be so frequent as to preclude anything like a high standard of regularity. But, as I have pointed out above, an Atlantic mail service can only be really effective if the start is made at night, and in any case it is almost inevitable that night operations must be included in the programme for an all-the-

year-round service. It appears, therefore, that if refuelling in flight is to be employed effectively it must be capable of being done regularly at night, and my own view is that this is inherently impracticable under winter conditions on both sides of the North Atlantic.

I hope that my remarks on the subject of refuelling in flight will not be misinterpreted as suggesting that there is definitely no future for this process. My remarks have been confined solely to its application to Atlantic services, for which the conditions of loading required are extreme and the conditions as to weather exceptionally bad. For services over other routes where the weather conditions are better and the requirements as to range and performance not quite so exacting, it may be that refuelling in flight could be utilised with considerable advantage, particularly if the airports involved did not provide satisfactory facilities for direct take-off at moderately high loadings.

STRATOSPHERE FLYING.

A good deal has been heard during the last few years about stratosphere or high altitude flying, especially in connection with trans-Atlantic services. The principal advantage to be gained by flying at high altitude is that, with suitable supercharging of the engines, a higher cruising speed can be obtained. There is also the possibility that the pilot may be able to find better average weather conditions at heights of 20,000 ft. or more. On the other hand continuous flying at these altitudes necessitates the provision of a pressure cabin to contain all members of the crew and any passengers carried. The pressure cabin need not be maintained at full sea level pressure, but only at some intermediate pressure such as that corresponding with a height of 8,000 ft. Nevertheless the provision of a pressure cabin even for this moderate pressure rise entails a considerable amount of additional weight and many difficult design problems. Aircraft with such pressure cabins are now under development and within the new few years a great deal more will be known about the possibilities in this direction.

So far as trans-Atlantic services are concerned the effective utilisation of high altitude flying represents a somewhat complex problem. It may be taken that increasing the operational height and supercharging the engines accordingly will increase the available cruising speed at the rate of about 1.5 m.p.h. per 1,000 ft. of altitude. This is an important gain, but unfortunately it cannot be realised in full for trans-Atlantic services, owing to the increase in the wind speed with height. Meteorological experts have estimated that the prevailing westerly wind increases at an average rate of about 2 m.p.h. per 1,000 ft. of altitude. It follows, therefore, that increasing the operational height of the aircraft will normally mean a loss of net speed for the westerly crossing.

On the other hand there will be a definite gain for the easterly crossing, and reference to the figures which I quoted earlier for effective times against cruising speeds will show that a substantial increase in speed on the easterly crossing would be a material advantage for a high speed mail service. If, for instance, the average westerly wind at a height of 25,000 ft. were assumed to be 60 m.p.h. instead of 20 m.p.h., and the cruising speed of the aircraft 330 m.p.h. instead of 300 m.p.h., the effective time for the easterly crossing would be reduced to 13.7 hours, and this would enable the delivery to be made in London at 10.45 a.m. instead of 12.30 p.m.—an appreciable advantage. The westerly wind at 25,000 ft. would probably often exceed 60 m.p.h. and the advantage would be correspondingly greater.

Unfortunately the conditions over the Atlantic, especially in winter, are frequently so bad that it is impossible for the pilot to fly at a predetermined height, and for this reason considerable flexibility in the operational altitude must always be provided for.

The case for stratosphere or very high altitude flying over the Atlantic does not appear to be strong and the balance of argument appears to favour a moderate

operational height of from 5,000 ft. to 10,000 ft. with ability to fly considerably above or below this height without appreciable loss of performance. This conclusion does not imply that the development of pressure cabins is not worth while, because recent experience is tending to show that continuous flying at heights above 10,000 ft. without cabin supercharging or a supply of oxygen may have a harmful effect. A moderate degree of cabin supercharging may therefore become necessary for all Atlantic aircraft.

The pressure cabin can, at a sacrifice in weight, be incorporated in any size of aircraft, but the smaller the size of aircraft the less the relative sacrifice in weight. The provision of a pressure cabin for the crew of a small high speed mail carrier is a relatively easy matter, but it is going to be a much more formidable matter in the case of a large passenger air liner.

Conclusion.

In a far too lengthy paper I have only been able to survey some aspects of this very wide subject, and there are, of course, many important technical problems which I have not even mentioned. I have tried to confine myself to the major issues, because it has seemed to me that there has so far been a general failure to face up to these major issues. Great individual flights and successful services of a seasonal and temporary nature have been trees which have obscured the wood, and what I have been trying to do is to give some sort of a view of the wood as a whole. It will be convenient perhaps to conclude with a very brief summary of the opinions expressed and the conclusions reached in the paper.

(1) Progress towards the establishment of worth-while trans-Atlantic services has been delayed by too much anxiety to get some sort of service started. There has been no considered policy which takes account of the major problems involved.

(2) The dominating factor controlling design progress has been and remains the strong prevailing westerly wind.

(3) The stage has not yet been reached when regular services over the North Atlantic can be attempted during the winter months.

(4) The aim should be the establishment of a reliable, regular and frequent all-the-year-round service.

(5) The extreme northerly route via Iceland and Greenland is impracticable.

(6) The base at Botwood, Newfoundland, is closed by ice for more than six months in the year.

(7) All the alternative North Atlantic routes are likely to prove impracticable with the marine type aircraft, except on the basis of through non-stop services to New York or beyond.

(8) The only route open to land type aircraft during the winter is the direct route via Newfoundland, but Newfoundland is in a bad weather area and a scheduled stop at Hatties Camp will be likely to cause serious irregularity.

(9) A scheduled stop at the base in Eire will be prejudicial to the establishment of regular services during winter.

(10) The only services likely to achieve good regularity during winter are through non-stop services from Great Britain to Montreal or New York.

(11) Only land type aircraft can be operated to Montreal during winter, and if marine type aircraft are employed the base must be New York or beyond with a shuttle service to Montreal with land type aircraft.

(12) If through services are established the bases in Eire and Newfoundland will not be wasted, because they will provide invaluable emergency landing places.

(13) To compete with shipping services and cable and telephone facilities Atlantic air services must be of high speed and high frequency. A mail service should be an overnight service with a daily frequency. A passenger service should make the whole journey within 24 hours but need not have so high a frequency.

(14) The cost of passenger services over the Atlantic will be far higher than that of mail services, and heavy subsidisation will be required if passenger rates are to be made reasonably attractive.

(15) The primary objective should be the provision of high speed mail services, and the provision of subsidised passenger services should be regarded as a secondary objective.

(16) The carriage of passengers by air over the North Atlantic during the winter months will not be justifiable for several years to come.

(17) There is a strong case for the segregation of passengers and mails.

(18) There is a strong case for establishing mail services on the basis of a surcharge, and excluding these services from the all-up mail scheme which applies in other parts of the Empire.

(19) The daily volume of surcharged mail in each direction is not likely to exceed 500 lbs. and a mail carrier with capacity for 1,000 lbs. would meet requirements for a long time to come.

(20) The range and cruising speed required for an Atlantic mail carrier are 3,400 miles against the prevailing wind and 300 m.p.h.

(21) The cruising speed for a passenger air liner should be a minimum of 200 m.p.h.

(22) To meet the performance requirements for the mail carrier it will be necessary to employ an initial wing loading of 50 lbs. per sq. ft. or more.

(23) The performance requirements can only be met with direct take-off by very large aircraft.

(24) With direct take-off very long runs over specially prepared runways or smooth stretches of water will be required, and the take-off and initial climb will be generally much more hazardous than with normal present day aircraft.

(25) The marine base at Southampton is not suitable for the operation of very heavily loaded flying boats. It is doubtful whether the degree of protection on the Shannon is sufficient for such aircraft during the winter months.

(26) No land airport suitable for the operation of very heavily loaded aircraft is at present available within reasonable reach of London.

(27) For an effective mail service the start must be made at night, and this requires specially good facilities whether for marine or land type aircraft.

(28) The flying and ground handling of large heavily loaded aircraft are likely to present considerable difficulties. In these respects the marine type aircraft is likely to be at an advantage.

(29) It is not at present possible to design a satisfactory and economic direct-take-off aircraft to meet the performance requirements for an Atlantic mail carrier.

(30) The catapult does not offer a satisfactory or complete solution to the problem of assisting the take-off of a heavily loaded aircraft.

(31) The catapult method of assisting the take-off can only be applied to aircraft of small or moderate size; it is not practicable to apply it to very large aircraft.

(32) The composite aircraft provides a safe, satisfactory and economic method of launching a comparatively small aircraft under extreme conditions of loading.

(33) By employing the composite aircraft method it is possible to design immediately an Atlantic mail carrier meeting all the performance requirements. Such aircraft can be operated from existing airports.

(34) The composite aircraft method is inherently suitable for night operations.

(35) The composite aircraft method is not suitable for the launching of large passenger aircraft.

(36) If the principle of segregation of passengers and mails is accepted, the composite aircraft offers the best solution to the problem of designing a suitable mail carrier, and its development for this purpose should be continued.

(37) Refuelling in flight offers a solution to the take-off problem for aircraft of moderate or large size, but not for heavily loaded aircraft of small size.

(38) It is doubtful whether refuelling in flight can be successfully applied to any aircraft of extreme loading.

(39) Refuelling in flight is not inherently suitable for night operations in bad weather conditions, and it appears improbable that it can be used successfully for regular North Atlantic services during the winter months.

(40) Refuelling in flight appears to have more scope for application for such services as those over the South Atlantic where the weather conditions are better and the conditions as to loading not quite so exacting.

(41) Stratosphere or high altitude flying has disadvantages as well as advantages for trans-Atlantic services, and the balance of argument appears to favour designing for a moderate operational height.

(42) Development of the pressure cabin for moderate pressure rises should be actively continued.

(43) SUMMARY.

The best hopes of establishing worth-while trans-Atlantic services appear to me to lie in aiming from the first at through non-stop services, segregating passengers and mails, developing at once a land type composite aircraft with extreme wing-loading for mail services, developing by stages the large flying boat with moderately high wing-loading for passenger services, and providing a suitable marine base in England for the operation of such flying boats.

NOTE.—The views expressed in this paper are the personal views of the author as an individual.

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Rifle Grenades. (C. Warringer, W.T.M., Vol. 43, No. 8, August, 1939, pp. 342-348.) (71/1 Germany.)

The earliest types of grenades were fitted with a stick which was inserted into the rifle barrel, the grenade projecting beyond the muzzle. As a subsequent development, the grenade was fitted with a central passage and placed in a separate funnel shaped container attached to the muzzle. The normal projectile of the rifle passed through this hole and the grenade was projected by the powder gases following the projectile. (Maximum range about 100 m. for .5 Kg. grenade.) It is obvious that the range could be increased if the leak through the grenade could be stopped. This naturally leads to the closed type of grenade, in which the rifle bullet becomes imbedded (Brandt). Although a range of up to 400 m. now becomes possible, the grenade has to be built to stand the impact shock and this detracts from its primary function as an efficient carrier of explosive. The increased range is almost entirely due to the sealing of the explosive gases and would be reduced by only 10 per cent. if the bullet were allowed to travel through the grenade without shock and means of sealing the passage after transit could be devised. The author described such an arrangement consisting of a spring loading flap valve which closes after the passage of the bullet. Differences in range at constant elevation can be obtained by a variable gas leak or by adjusting the distance of the grenade from the muzzle exit.

High Explosive Bombs. (T. L. Davis, Army Ordnance, Vol. 20, No. 116, September-October, 1939, pp. 91-94.) (71/2 U.S.A.)

Anti-Personnel bombs must explode as soon as they touch the ground. Bombs for the destruction of buildings on the other hand must penetrate before exploding, i.e., the explosive must be insensitive enough to stand the shock of impact and only respond to a separate fire mechanism functioning with a definite delay. Both types of bomb fillings must not explode if accidentally struck by bullets or shell splinters whilst being carried by the aircraft.

Dynamite and other explosives containing nitroglycerine are much too sensitive for bomb filling. The usual explosive for this purpose is T.N.T. (trinitrotoluene). In cases where destruction by " blast " is effective, trinitro benzene is recommended.

A lot has been heard about liquid oxygen as a constituent of bomb fillings. Mixtures of liquid oxygen and cork dust or powdered aluminium form powerful and safe explosives. Unfortunately the liquefied gas evaporates and the explosive

must be used very soon after preparation in order to be effective. As an alternative, liquid NO_2 can be used in closed containers. Mixed with CS_2 or petrol it forms the explosive called anilite. T.N.T. does not contain enough oxygen for complete combustion and thus produces a black smoke. This difficulty is overcome by the addition of ammonium nitrate, the mixed product being known as amatol. The ammonium nitrate is itself explosive and since it contains an excess of oxygen the addition of powdered aluminium is very effective. It is very likely that the German bombs used in Spain and described in the press as containing an explosive made from air, contained ammonium nitrate since the latter is a by-product of the fixation of atmospheric nitrogen.

Bomb Release with Climbing Flight. (C. Rougeron, Nova Air Revue, No. 45, August, 1939, pp. 2-5.) (71/3 France.)

The object of bomb release while climbing is to increase the range (horizontal trajectory) of the bomb. This forces the defending A.A. artillery to be distributed over a much larger area and naturally reduces the fire density. Conditions most favourable to the bomber thus arise if a coast line is attacked.

Large increases in bomb range are only possible if the bomb is launched by means of an aircraft gun or if some method of rocket propulsion is employed. The actual range obtained will depend markedly on the weight and design of the bomb.

The author is of the opinion that ranges of the order of 10-20 Km. should be possible in the near future. If stratosphere bombers are employed, the possible range would be extended to 50 Km. and beyond. Such a high release causes the bomb to travel for a considerable part of its trajectory in air of very low density and the ballistic problem thus resembles that of the long range gun.

Co-operation Between A.A. Artillery and Fighters. (L. Gretschkosy, Luftwehr, Vol. 6, No. 7, July, 1939, pp. 296-7, from the Russian.) (71/4 U.S.S.R.)

Three types of co-operation are possible:—

1. Zone of operation of fighter is limited to certain altitudes (*a*), or he is instructed to keep above certain landmarks (*b*).
2. The artillery and the fighters attack different targets.
3. Artillery and fighters attack same target simultaneously.

1a. The disadvantage of altitude co-operation is the fact that the enemy is likely to pass rapidly from one zone to the other, and if he happens to operate in the intermediate safety zone previously laid down he may escape attack for a period. Moreover by arranging the method of attack according to altitude, the bomber is able to adopt the type of formation most favourable to him, i.e., close formation above the A.A. zone and open formation below it.

1b. Keeping above certain landmarks is extremely difficult for the fighter, unless he is in constant telegraphic touch with the ground batteries. This naturally detracts from his fighting capacity.

2. If fighter and A.A. are to attack different targets, priority is generally given to the artillery, which attempts to break up the enemy formation which is then attacked by the fighters.

3. Simultaneous attack with fighters and artillery can be carried out in two ways.

(*a*) The bomber formation is fired at from the ground and also attacked laterally by means of multiseat fighters whilst single seat fighters attempt to drop bombs on them from above.

(*b*) The artillery fire is in salvos, the fighters attacking between the periods of rest arranged previously. This necessitates frequent change of course for the fighters, and puts the crews of the latter to great physical strain, thus impairing their fighting efficiency.

The most difficult form of co-operation exists if the enemy appears suddenly out of the clouds. If the possibility of such an attack can be foretold from acoustical records, the A.A. artillery must open a barrage fire. The rôle of the fighter will then be to keep in as close contact as possible with the enemy and correct the artillery fire.

It will be noted that all co-operation between fighters and A.A. artillery depends on the efficiency of the means of communication between the two. Wireless and especially optical signals are relied on. The time available is however very short and the signals must therefore be of the simplest type.

Effective co-operation thus entails lengthy practice under simulated war conditions.

Explosives for Aerial Bombs (from the Italian). (Rev. de l'Arm. de l'Air, No. 117, August, 1939, pp. 445-6.) (71/5 Italy.)

In the 1914 war, the principal explosives were picrid acid (melinite) and T.N.T. The latter requires 400 kg. of coal for 1 kg. of explosive and an aerial bomb of 2,000 kg. is thus equivalent to a trainload of coal.

As a result, alternative methods of manufacturing explosives have been considered, which take CO as a starting point. This is hydrogenated, producing in turn methyl alcohol and formaldehyde. The latter acts as basis for four complex explosives,

pentrite (tetranitrate of pentærythrene)
T_4 (trimethylene trinitroamine)
tetranitrate of isobutylglycerine
peroxide of hexamethylene diamine

Only the first two of these are of interest for aerial bombs. Although the cost is over twice that of T.N.T., the expenditure may be justified in view of the fact that these explosives are 50 per cent. more powerful that T.N.T. and the weight of the bomb is thus reduced. Although the finished product is very stable, the filling process is complicated by the fact that fusion and decomposition temperatures are relatively close. For this reason the new explosives are often mixed with other products to reduce the sensitivity. We thus have the pentrinite of Prof. Stettbacher (pentrite + nitroglycerine), the Bonite of Bofors (T_4 + T.N.T.) and finally the product of the Italian chemist Tonegutti (pentrite + Ammonium nitrate + dicyanodiamide).

Present Position Concerning Nature and Consequences of Barrel Wear. (D. Bornemann, Z.G.S.S., Vol. 34, No. 9, September, 1939, pp. 267-269.) (71/6 Belgium.)

Barrel wear is most marked at a distance of a few calibres from the beginning of the rifling and near the muzzle. If cartridge ammunition is used, the unrifled barrel in the neighbourhood of the neck of the casing (i.e., on a level with the base of the projectile) also shows signs of wear.

The wear originates in the friction generated in the rifling and is aggravated by gas leakage. It can be controlled by proper choice of barrel material, type of explosive and type of mounting for guide ring on shell.

The main effect of wear is a large decrease in range arising from oscillations of the projectile in its trajectory (canting of projectile on leaving muzzle).

The muzzle velocity is also diminished. It is, however, interesting to note that maximum muzzle velocity is only reached after a new gun has fired a certain number of rounds. This is attributed to a polishing effect inside the barrel which subsequently is destroyed by wear producing the drop in muzzle speed referred to above.

Speaking generally, cartridge ammunition is the worst offender in this connection.

Effect of Transition in Cross-Sectional Shape on the Development of the Velocity and Pressure Distribution of Turbulent Flow in Pipes. (E. Mayer, Forschungsheft, Vol. 9, No. 389, March-April, 1938. N.A.C.A. Tech. Memo., No. 903, August, 1939.) (71/7 Germany.)

In this paper the results are presented of pressure and velocity distribution measurements in transition pieces in order to investigate the effect of the change in shape of the cross section contour for equal area of cross section. For the two investigated transition pieces (which differed in their transition lengths) a circular cross section is deformed into one of rectangular shape.

The most important factors affecting the velocity and pressure distribution in the transition pieces are enumerated and it is attempted to show their effects at least qualitatively. The greatest effect is that produced by the local retardations and accelerations.

It is concluded from the measurements for the transition rectangle circle that the change in turbulence mechanism due to the cross section deformation does not very greatly affect the velocity distribution in the transition cross sections themselves. The change in the friction perimeter of the cross section due to the deformation is, however, important.

At the conclusion of the paper are given the loss coefficients for the two transition pieces in both flow directions.

Universal Logarithmic Law of Velocity Distribution as Applied to the Investigations of Boundary Layer and Drag of Streamline Bodies at Large Reynolds Number. (G. Gurjienko, Trans. C.A.H.I., No. 257, 1936. Available as Air Ministry Translation T.M. 842.) (71/8 U.S.S.R.)

The Karman expressions for the velocity distribution in a boundary layer and the surface drag both include a so-called " universal " constant. Up to now the value of this constant was deduced from experiments on the flow in pipes (Nikuradse) and it was assumed that the same value of the constant applied both in the velocity distribution and surface friction expressions. Assuming a value of .4 for this constant, the authors have calculated the thickness of the boundary layer in the case of the " Acron " airship hull, with the result that the theoretical values are approximately 50 per cent. greater than those given by experiment.

In order to remove this discrepancy, the author suggests a " compromise " law, in which the universal constant has a value .2 to .3 in the velocity distribution formula and a value .4 in the expression for the drag in the laminar sublayer.

The article shows how the integration of the pertinent equations is simplified by the use of functional scales which are given in an appendix. By means of these scales calculations can be readily carried out for any value of the "Universal" constant and in the case where another logarithmic law (e.g., that of Nikuradse-Prandtl) is adopted.

D.2 Aerofoil Series. (E. Solodkin, Trans. C.A.H.I. No. 264, 1936.) (71/9 U.S.S.R.)

The D.2 series varies in thickness ratio σ from $\sigma = .1$ to $\sigma = .22$, the value of the maximum lift coefficient being rather high (.69 referred to ρv^2) and the lift/drag ratio varying from 15 to 21 at $Re \sim 10^6$.

Tests show that a whole span split flap fitted to these aerofoils causes an increase in maximum lift which can be represented by the following empirical equation.

$$C_{L\max} = .75 - 7.43\ (.29 - \sigma)^{1.82}.$$

As a criterion for the effect of the flaps on landing speed, the ratio of the maximum lift coefficient with flap to that without can be used. This ratio varies linearly with thickness ratio and can be expressed by

$$(C_{L\max} \text{ with flap}) / (C_{L\max} \text{ without flap}) = 1.25 + 3.666.$$

It must be remembered that both the above formulæ only apply to aerofoils of the D.2 family, the pertinent parameters of which are given in the report (maximum thickness well forward, slight upward curvature of trailing edge).

Effect of Proximity of the Ground on the Aerodynamical Characteristics of an Aeroplane. (I. Serebrijsky, Trans. C.A.H.I. No. 267, 1936.) (71/10 U.S.S.R.)

The experiments by the author were carried out by the well known " image " method, a special suspension enabling the two models to be displaced simultaneously and symmetrically. Only the case of steady horizontal flight near the ground is investigated and the results obtained are considered to be in sufficiently good agreement with theoretical calculations in which the wing is replaced by a Helmbold Vortex system. Some experimental data on the longitudinal stability of a wing in close proximity to the ground are given and the author concludes with a critical examination of experimental methods for the determination of the ground effect.

Note by Abstractor.—As was pointed out by Grusoon (Comp. Ren. No. 7, 15/2/37), the image method gives misleading results in the case of interference between the vortices shed by the two models. A new vortex street is formed and the ground effect is no longer represented.

The Use of Heavy Gases or Vapours for High Speed Wind Tunnels. (I. A. Rubinsky, J. Aeron. Sci., Vol. 6, No. 11, Sept., 1939, pp. 446-450.) (71/11 U.S.A.)

In order to take into account the effect of compressibility model tests must be carried out at the same Mach number as full scale. This means that the tunnel speed must be practically the same as under actual conditions. By replacing the air in the tunnel with a gas of higher molecular weight, C, the speed of sound is reduced and since Mach number $= V/C$, the tunnel speed V can be lowered without affecting dynamic similarity. This in its turn reduces the power required to operate the tunnel very considerably, but introduces experimental difficulties (sealed tunnel and remote controls).

The author gives a preliminary design for a heavy vapour tunnel utilising carbon tetrachloride. The gas speed is 650 feet/sec., giving a Mach number of 1.3 and the experimental section is 1 sq. ft.

The h.p. required for this installation will be of the order of 250, which is less than 10 per cent. of the power required when operating with air at the same density and the same Mach number.

The Aerodynamic Characteristics of Six Full-Scale Propellers having Different Aerofoil Sections. (D. Biermann and E. P. Hartmann, N.A.C.A. Report No. 650, 1939.) (71/12 U.S.A.)

Wind-tunnel tests are reported of six 3-blade 10 ft. propellers operated in front of a liquid-cooled engine nacelle. The propellers were identical except for blade aerofoil sections, which were: Clark Y, R.A.F. 6, N.A.C.A. 4,400, N.A.C.A. 2,400-34, N.A.C.A. 2R 200, and N.A.C.A. 6,400. The range of blade angles investigated extended from 15° to 40° for all propellers except the Clark Y, for which it extended to 45°.

The results showed that the range in maximum efficiency between the highest and the lowest values was about 3 per cent. The highest efficiencies were for the low-camber sections. An analysis of the results indicated that blade sections for controllable propellers which are not limited in diameter should be selected chiefly on a basis of minimum drag (which affects maximum efficiency) inasmuch as the maximum lift coefficients had only a small effect on the take-off characteristics within the range investigated because stalling, in general, did not occur.

Sections for fixed-pitch propellers should be selected on a basis of both minimum drag and maximum lift, particularly for blade-angle settings of 20° and over, because the take-off thrust power increased with maximum lift for the higher blade angles.

Flight Tests of N.A.C.A. Nose-Slot Cowlings on the BFC-1 Aeroplane. (G. W. Stickle, N.A.C.A. Tech. Note No. 720, August, 1939.) (71/13 U.S.A.)

The results of flight tests of four nose-slot cowling designs with several variations in each design are presented. The tests were made in the process of developing the nose-slot cowling. The results demonstrate that a nose-slot cowling may be successfully applied to an aeroplane and that it utilises the increased slipstream velocity of low-speed operation to produce increased cooling pressure across the engine. A sample design calculation using results from wind-tunnel, flight, and ground tests is given in an appendix to illustrate the design procedure.

Adhesion of Ice in its Relation to the De-Icing of Aeroplanes. (A. M. Rothrock and R. F. Selden, N.A.C.A. Tech. Note No. 723, Aug., 1939.) (71/14 U.S.A.)

The most important conclusions drawn from the present tests are possibly not new, but they seem to be quite definite.

1. Ice will adhere to any solid surface tried thus far with a force greater than the cohesive forces within the ice.

2. Ice will not adhere to a surface provided that there is a liquid interface between the ice and the surface. If such a liquid interface is formed, the force required to remove the ice will be little more than the aerodynamic or aerostatic forces tending to hold the ice to the surface.

3. The outlook for preventing ice formation on the surfaces of an aeroplane wing by means of some liquid surface is not encouraging. The amount of liquid required will probably be large and some mechanical force is necessary to overcome the air forces in order to remove the ice. The use of such liquids for windshield de-icing or for small surfaces may be successful.

4. For propellers, where a centrifugal force is always available, the use of liquids for de-icing will probably continue to be the most efficient method.

5. Although wind-tunnel tests have indicated that heating the wings of an aeroplane as a means of preventing ice formation is feasible, no full-scale tests have been made to determine the practicability of the method. It is believed that such tests should be conducted as soon as possible.

The Effects of Surface Waviness and of Rib Stitching on Wing Drag. (M. J. Hood, N.A.C.A. Tech. Note No. 724, Aug., 1939.) (71/15 U.S.A.)

CONCLUSION.

1. Surface waviness of a magnitude common to aeroplane wings will not seriously increase the drag unless the waviness exists on the forward part of the wing, where it may cause premature transition or premature compressibility effects. Waves 3 inches wide by 0.048 inch high, for example, increased the drag about 1 per cent. when the waves covered the rear 67 per cent. of both surfaces and 10 per cent. when they covered the rear 92 per cent.

2. A single wave 3 inches wide by 0.020 inch high at the 10.5 per cent. chord position on the upper surface was just high enough to cause transition to occur at the wave. The resultant drag increase was 6 per cent.

3. Rib stitching corresponding to a rib spacing of 6 inches increased the drag 7 per cent.; the drag increment was proportional to the number of ribs for larger rib spacings. About one-third of the increase was due to the premature occurrence of transition at the forward ends of the stitching.

In all the above cases the lift coefficient is .15 and the Reynolds Number 10.3×10^6.

Effect of Engine Nacelles and Undercarriage on the Characteristics of a Thick Monoplane Wing. (V. Gorsky, Trans. C.A.H.I. No. 259. Available as Air Ministry Translation No. 529.) (71/16 U.S.S.R.)

The experiments were carried out on a model wing of 1.5 m. span and .2 m. chord, double convex profile, with a maximum thickness ratio of 20 per cent. Nine different types of engine nacelles were used, the number on the wing varying from 6 to 12. Four separate types of undercarriages were tested. The wind speed varied between 10 and 50 m./sec. On account of the relatively small value of the Reynolds number, extrapolation to full scale is uncertain. It is, however, considered that the relative values obtained give some guide to the designer.

The following are some of the principal conclusions.

1. The engine nacelle disturbs the distribution of the circulation on the wing and is equivalent to an induced resistance which may be several times greater than the head resistance of the nacelle tested separately.
2. Maximum induced resistance is caused by engine installations above the wing or by nacelle situated near the leading edge especially if the size of the nacelle is relatively great compared with the thickness of the wing.
3. The best position appears to correspond to the axis of the nacelle being slightly below the wing chord.
4. The detrimental effect generally increases as the distance between the nacelles becomes less.
5. The interference effects of the undercarriage are very small.
6. The experiments show the importance of cowling the radiators.

Wind Tunnel Investigations of Aeroplane Spin, Taking into Account the Radius of the Trajectory. (A. Jouravchenko and E. Verjanskaia, Trans. C.A.H.I. No. 260.) (71/17 U.S.S.R.)

It is very difficult to mount a spinning model on a balance except for the case $r=0$ (radius of trajectory zero). This entails certain corrections which must be applied for the general case $r \neq 0$. The authors determine these corrections theoretically and show that they are only of importance in the case of the centrifugal forces and rolling moments. By arranging so that the ellipsoid of inertia of the model becomes a sphere, the centrifugal moments disappear when $r=0$ and the correction for the general case becomes very simple.

The procedure adopted by the author is so simple that the mathematical analysis can be carried out simultaneously with the experiment.

Effective Loads on Undercarriage. (S. N. Chichkine, Trans. C.A.H.I. No. 269, 1936.) (71/18 U.S.S.R.)

The loads on various parts of the undercarriages of two aircraft of 2 ton weight were measured by means of extensometers during landing and take off. Records of time/stress showed that the impact (shock) load during a normal landing may exceed the static load of 3.25 times.

The results are utilised for a proposed revision of load factors of landing gears.

Alighting of Flying Boats on a Heavy Sea and in the Dark. (W. Parker, Flugsport, Vol. 26, 1934, pp. 51-54 and 73.) (71/19 Germany.)

The author favours the provision of drag ropes about four times the length of the machine. Warning of the approach of the water surface is thus given to the pilot under conditions of bad visibility and the drag of the rope in the water materially reduces the landing run. It is very important that the rope should be attached near the C.P. of the aircraft so as to introduce no considerable pitching movement. Some rubber damping by means of an elastic attachment must also be provided to reduce the shock of impact of the rope with the waves at the instant of contact. As every seaplane must already carry a sea anchor, the extra weight

due to the drag rope for alighting can be kept small. After discussing various methods of towing seaplanes, the author refers especially to the landing sail of Hein. This consists of a sail towed behind the ship and kept flat by means of transverse laths. Tubular compartments are fitted on the underside through which the water flows as the sail is dragged along and this assists in steadying the sail. Lateral floats produce the necessary buoyancy. The sail is dragged against the wind and the seaplane runs on to the sail at a high speed and after coming to rest can be towed even in a rough sea. Communication between ship and plane is simplified and even small repairs can be carried out. The surface of the sail protects the aircraft from spray and by flooding the sail (i.e., reducing buoyancy of floats or reducing drag speed) the seaplane parts company with the sail if a new take-off is contemplated.

Abstractor's Note.—A landing sail in the rolled up condition is shown in Engineering, Vol. 144 (1937), p. 100, whilst some descriptive matter is contained in an article entitled " The Seaplane Catapult Ship ' Ostmark ' " on pp. 109-110 of the same journal.

Tank Tests to Determine the Effects of the Chine Flare of a Flying Boat Hull. (J. W. Bell and R. E. Olson, N.A.C.A. Technical Notes No. 725, August, 1939.) (71/20 U.S.A.)

Twenty-two models of flying-boat hulls were tested in the N.A.C.A. tank for the purpose of determining the effects on water resistance and spray of 13 variations in the transverse section of the bottom of the forebody and of three variations in the form of the afterbody. The forebodies were of the same overall dimensions and differed in the type and amount of chine flare. The afterbodies included one with a pointed plan form and straight buttocks, one with a second step and straight buttocks, and one with a second step and concave buttocks. The depth of the step at the keel was the same in all models. Conclusions:—

1. The height of the spray originating where the chine of the model was above the water level was reduced by the chine flare.
2. The height of the spray originating at the side of the portion of the chine that was below the water level was not reduced by the chine flare. In some cases, the height of this spray was increased by chine flare.
3. The resistance at best trim at the hump and at high speeds was only slightly affected by chine flare.
4. The resistance at best trim at intermediate planing speeds was reduced by chine flare.
5. In the free-to-trim tests, the trim and the resistance at the hump were increased by chine flare.

Present Position and Future Prospect of Transoceanic Aviation. (F. V. Buddenbrock, W.R.H., Vol. 20, No. 18, 15/9/39, pp. 283-289.) (71/21 Germany.)

Transoceanic aviation has been on trial over three major ocean routes: the South Atlantic, the Pacific and lastly the North Atlantic. Of these the first presents the smallest meteorological difficulties and a regular postal service has been in operation over this route for several years by German and French machines. The latest German seaplanes on this route average 280 Km./$_h$ over the 3,000 Km. Bathurst-Natal, the total time for the post to reach Rio from Frankfurt-Main being generally less than 2½ days. Between February, 1934, and the spring of 1939 there have only been seven cases of delay, amounting to 1-2 days, the majority of the causes being connected with the feeder lines and not the main ocean crossing. A fair amount of experience has also been gained on the Pacific route, which is operated by American Flying Boats. The regularity of this service, however, leaves much to be desired. The North Atlantic route is by far the most difficult and in spite of propaganda is not yet ripe for a regular passenger service through-

out the year. The author considers it a great mistake to operate such a passenger service without previous experience of postal traffic. According to him the North Atlantic service requires flying speeds of the order of 580 $Km/_h$ in order to make it attractive. Such a speed would render a night crossing possible. It is probable that medium-sized flying boats (15-50 passengers) will hold the field for oceanic crossings for some time (mainly because expensive landing grounds are not required). It is unlikely that the huge flying boat projects discussed lately in the press and carrying 100 and more passengers will materialise except in the very distant future.

The Effect of Fixed Wing Slots on the Stall Characteristics of a Modern Bi-Motor Aeroplane. (C. L. Johnson and R. L. Thoren, J. Aeron. Sci., Vol. 6, No. 11, September, 1939, pp. 437-445.) (71/22 U.S.A.)

A major design problem of modern aircraft is to combine high performance with good flying qualities. Blind flying especially calls for low speed manœuvrability and stability together with favourable stall characteristics.

Flight tests on the Lockheed 14 transport aircraft showed that the stall was preceded with insufficient warning for the pilot and was combined with a high rate of roll, particularly in the case of a power stall. This trouble was overcome by incorporating fixed wing slots covering less than 10 per cent. of the wing area over $\frac{1}{4}$ of the wing span near tip. The author describes quantitative measurements of the stall, using special equipment such as left and right hand aileron deflection indicators, as well as elevator and rudder angle indicators (all these operated on the D.C. Selsyn system).

The angle of attack was measured with a special instrument consisting of a small low aspect ratio aerofoil with a pressure orifice near the leading edge. When suitably dimensioned, the pressure recorded by this instrument is a function of the angle of attack only (independent of air speed).

The stalling of the air flow on the wing was recorded on a cine camera (wool tufts).

It is stated that although the drag of the wing section behind the slot is probably doubled, the percentage of this wing area to the total is so small that the net effect of fitting these slots on speed and climb is negligible.

An Analysis of the Problem of Ice on Aircraft. (W. C. Geer, J. Aeron. Sci., Vol. 6, No. 11, Sept., 1939, pp. 451-459.) (71/23 U.S.A.)

After briefly discussing meteorological conditions responsible for ice formation on aircraft, the author describes the principal methods which have been suggested or tried for overcoming this danger, classifying them according to the particular part of the aircraft to be protected, i.e. :—

1. Windshields and windows.
2. Propellers.
3. Wings, struts and other aerodynamically shaped surfaces.
4. Ailerons and control surfaces.
5. Pitot static.
6. Radio parts.
7. Carburettor.
8. Nose, pontoons and fuselage.
9. Air scoops and edges of other open channels.
10. Landing and running lights.
11. Projections on wing surface.

Although none of the schemes (chemical, mechanical or thermal) may claim any finality it is a fact that the ice hazard has been reduced during recent years. The ultimate goal of safety under all ice conditions is however still far off.

A useful bibliography of 71 items concludes this interesting paper.

Boiler and Turbine in One. (Power, September, 1939, p. 65. Metropolitan-Vickers Tech. News Bull., No. 676, 15/9/39, p. 5.) (71/24 Great Britain.)

This article briefly describes the Huettner rotative boiler-turbine, which combines a steam generator air heater and fan, steam turbine and a condenser in one unit. Greatly reduced weight and space requirement is claimed, there being virtually no auxiliary machinery. The steam path and the course of the condensing water and air supply to the burners in the furnace are described and indicated by means of a diagram for a 100 kw. unit. It is estimated that the total weight of a 500 h.p. unit is 2.5 lb./h.p. and for a 2,000 h.p. unit about 1.7 lb./h.p. Space requirements are said to be comparable with those of an electric motor of the same output.

Illustrated with one diagram.

Constant Pressure Blowers. (E. Sorensen, Z.V.D.I., 12/8/39, pp. 925-931. Metropolitan-Vickers Tech. News Bull., No. 673, 25/8/39, p. 9.) (71/25 Germany.)

The author first considers the general and physical bases of axial and radial blowers, and the adoption of the constant pressure principle in the so-called Schicht blower. He then deals with the mathematical bases of the constant pressure blower, the importance of the diffuser of the constant pressure blower, and the design of the latter. In conclusion he gives a number of examples of actual constant pressure blowers, together with the results of tests, and refers to the application of the constant pressure principle to pump design.

Illustrated with fourteen diagrams and two photographs.

Blowers: Their Types and Dimensions. (O. Schmidt, Archiv. fur Warmewirtschaft, August, 1939, pp. 213-7. Metropolitan-Vickers Tech. News Bull., 25/8/39, p. 9.) (71/26 Germany.)

The author first discusses the advantages and disadvantages of axial blowers, following which he considers radial blowers (blading, arrangement, shape of impeller, losses, dimensions and method of suction).

Illustrated with twelve diagrams.

Attributes of the Buchi Exhaust Turbo-Charging System. (Oil Engine, Sept., 1939, pp. 157-8. Metropolitan-Vickers Technical News Bulletin, No. 677, 22/9/39, p. 9.) (71/27 Great Britain.)

In the Buchi system of supercharging for Diesel engines use is made of the exhaust gas energy, in a turbine driver blower to obtain a supply of pre-compressed air; 30 to 40 per cent. of the compressed air is used for scavenging. The air pressure at the end of the exhaust process during scavenging must be low since the flow is dependent on the difference in pressure between the inlet and exhaust manifolds. To achieve this, the method of working, which is described, creates abnormally large and suitably timed exhaust pressure fluctuations before the turbine.

Illustrated with two photographs and one diagram.

Compression-Ignition Engine Performance with Undoped and Doped Fuel Oils and Alcohol Mixtures. (C. S. Moore and H. H. Foster, N.A.C.A. Tech. Note, No. 707, Aug., 1939.) (71/28 U.S.A.)

1. Fuel oils of high cetane number gave no more power than fuel oils of low cetane number but had less ignition lag, lower rates of pressure rise, and smoother engine operation over a complete load range at 2,000 r.p.m.

2. Increased engine speeds and boost pressures resulted in smoother engine operation and permitted the use of fuel oils of low cetane number.

3. Fuel dopes decreased ignition lags and rates of pressure rise and increased smoothness of engine operation. The addition of 4 per cent. tetranitromethane increased engine power by less than 3 per cent.

4. Fuel dopes improved neither the completeness nor the effectiveness of combustion.

5. Alcohol as an auxiliary fuel, in general, decreased power as the proportion of alcohol increased. Any increases in power obtained by double injection did not exceed 4 per cent. and were obtained at the expense of increased fuel consumption. Alcohol increased the ignition lag, the rate of pressure rise, and the roughness of operation.

Design of N.A.C.A. Cowlings for Radial Air-Cooled Engines. (G. W. Shickle, N.A.C.A. Rept. No. 662, 1939.) (71/29 U.S.A.)

The design of a cowling may be divided into two parts: (1) The Nose Section, and (2) the Exit Slot. The functions of these parts are distinct, the function of the nose being to allow the cooling air to enter and provide a smooth separation between the internal and the external flow. The amount of air flowing over the engine is controlled by the Exit Slot. The flow inside the cowling is profoundly affected by baffle plates, which thus form an important feature of good cowling design. The general direction of the air flow at the entrance to the cowling is radial, i.e., it approximates to that round a blunt nosed body. The percentage of air entering is small and the velocity at entry is low. The function of the nose of the cowl is to turn this low velocity air stream through 90°, i.e., to render it parallel to the main air stream, the space available being the distance between the rocker boxes of the engine and the trailing edge of the propeller. It has been found possible to cover normal requirements with only one shape of nose, a second shape being reserved for flying speeds above 350 m.p.h.

The performance of the cowl is much more sensitive to exit slot design than to entry and the author devotes considerable space to the determination of optimum size and position of this slot. The paper concludes with an estimation of the drag associated with the passage of the cowling air and of the drag increase caused by the addition of an N.A.C.A. cowl to the nose of a stream-lined fuselage. In the case of a single engined fighter, with a top speed of 300 m.p.h. and a climbing speed of 150 m.p.h. fitted with an engine of 16.5 sq. ft. frontal area developing 1,000 h.p. at take off, the extra cooling drag due to the passage of the air amounts to only 20 h.p. both for level and climbing flight.

The total increase in drag over a streamlined shape (without internal air flow) corresponds however to over 120 h.p. at 300 m.p.h.

On the Sodium Line Reversal Method of Determining the Temperature in a Gasoline Engine. (U. Yosida, Aer. Res. Inst., Tokio Report, No. 177, June, 1939.) (71/30 Japan.)

The sodium line reversal method of determining the temperature of a flame was applied to engine combustion. A special cylinder, with two quartz windows, was constructed, the light beam passing through combustion space.

A tungsten pointolite, a tungsten lamp, and a carbon arc lamp were used as the light source, a small quantity of sodium ethylate being added to the fuel.

The D-line intensity of the engine flame was measured by a photoelectric cell.

The spectrum in the visible region of the engine flame consisted of C.H. 4,300 A°, C.C. Swan bands, and the continuous bands. The spectra obtained at various crank angle, showed that the temperature in the cylinder is not uniform.

The maximum temperature at various air fuel ratios was measured with the engine running at 800 r.p.m. Although the correct air fuel ratio in the fuel under test was 13.8, the temperature was always maximum at 11.5, which is higher than

that obtained by Hersley and Panton[1] and agrees nearly with the calculated value, taking into account dissociation and heat loss.

Aviation Fuels and Engines. (F. R. Banks, J.S.A.E., Vol. 45, No. 3, September, 1939, pp. 389-406.) (71/31 Great Britain.)

PRINCIPAL CONCLUSIONS.

1. At the moment, the standard fuel for high powered British aero engines contains not more than 4 cc. of T.E.L. per gallon and has a rating of 87 octane by the C.F.R. modified Motor method.

2. Fuel of higher rating is under development. Satisfactory rating of such fuels can only be carried out in full scale cylinders.

3. British engines are considered by the author to be generally in a better position to utilise " temperature sensitive fuels " than American engines. This is attributed by the author to reduced swirl of the 4 valve British design.

4. Direct fuel injection into the cylinder as practised in some German engines is considered a most promising development both for power and economy.

5. Exhaust valves of the standard (poppet) type can now be designed which, together with their seats, stand up satisfactorily to all requirements and the sleeve valve is not considered to possess the outstanding advantage claimed for it. " Stellite " is now being replaced by a new nickel chrome alloy " Brightray " for treating valve heads and seats.

6. The Sinterkorund sparking plug developed by Siemens (sintered A1 oxide insulator) represents marked advantages over other types of plugs in high duty engines using leaded fuels. These plugs are fitted with very thin earth wires which reduces servicing costs.

7. Compression ignition engines have no chance of general adoption until the ratio of take-off to cruising power can be very considerably improved.

Coal Suspension in Light Oils as an Engine Fuel. (F. W. Godwin, Sci. Am., Vol. 161, No. 3, Sept., 1939, p. 159.) (71/32 U.S.A.)

The coal is ground to 300 or 500 mesh, chemically stabilised and suspended in either petrol or light fuel oil. It is stated that the fuel behaves satisfactorily in a standard motor car engine, provided the latter is first warmed up on normal petrol.

The coal suspensions have also been used satisfactorily in many types of commercial or domestic burners for heating.

The new process promises a field of application for the tremendous amounts of " fines " which are a waste product at the mines.

Boundary Friction in Bearings at Low Loads. (L. M. Tichvinsky, E. G. Fischer, J. App. Mech., Vol. 6, No. 3, Sept., 1939, pp. 109-113.) (71/33 U.S.A.)

The paper describes bearing tests performed in the region of semifluid or boundary lubrication. Bearings 2½ in. in diameter mounted in a rigid housing were loaded lightly and their performance studied in an attempt to correlate it with various physical properties of the bearing and journal materials. In this connection special consideration was given to journal surface finish and its measurement.

Within the inherent limits of the experiment it was shown that various journal materials, similarly machined and ground, perform differently in a babbitt shell. A higher value of the coefficient of friction was associated with a relatively rougher journal finish having grinding scratches of the order of 100 micro inches. Such finish in turn was associated with soft journal materials (180 Brinell).

The boundary oil film, formed between several grades of bearing materials and a chromium-plated journal, offered different frictional resistance to motion. In

[1] Hersley and Panton, *Engineering*, Vol. 137 (1935), p. 623.

the combinations of different bearing materials and the same chromium-plated journal, babbitt proved to be superior to bronze or silver.

The Thick-Film Lubrication of Full Journal Bearings of Finite Width. (M. Muskat, F. Morgan, J. App. Mech., Vol. 6, No. 3, September, 1939, pp. 117-121.) (71/34 U.S.A.)

A discussion is given of the results of analytical and experimental studies of the thick-film lubrication of full journal bearings of finite width. The Reynolds differential equation has been solved by a successive approximation method for (*a*) flooded full journal bearings, (*b*) full journal bearings with central circumferential grooves, and (*c*) full journal bearings provided with point sources of lubricant. Calculations were made on the variation of the journal eccentricity, load-carrying capacity, and friction coefficients with the Sommerfield dimensionless variable for the three cases and for different bearing widths. Direct experimental tests are described which confirmed the theoretical predictions for bearings fed with lubricant at point sources.

Ignition Lag in Compression Ignition Engines. (S. G. Bauer, Engineering, Vol. 148, No. 3846, 29/9/39, pp. 368-369.) (71/35 Great Britain.)

The engine experiments of the author are arranged so that firing always starts (i.e., ignition lag terminates) at T.D.C. He then attempts to connect the experimental delay period between beginning of injection and appearance of flame (measured stroboscopically, utilising a window in the cylinder) with the pressure and temperature existing at T.D.C. The function proposed is of the type

$$T \log p = f(t)$$

where T = absolute temperature at T.D.C.
p = absolute pressure at T.D.C.
t = ignition lag in milliseconds.

Whilst there may be some justification for an equation of this type for delay experiments in a vessel in which both p and T remain practically constant during the delay period, in the engine both these factors vary and it is not at all clear why the end or T.D.C. values only should be decisive.

In the author's own words in another part of the paper: "Considering the very involved nature of such measurements, luck must have been favourable to obtain such close agreement."

An Accelerated Oxidation Test for Oils. (W. Francis and K. R. Garrett. J. Inst. Petrol, Vol. 25, No. 190, August, 1939, pp. 501-5.) (71/36 Great Britain.)

The various modifications of the Michie (air bubbling) sludging test that are in use for measuring the oxidizability of an oil are difficult and laborious methods. A new method for determining the oxidizability of oil is described, using a solution of alkaline potassium permanganate under standard conditions as oxidizing agent. The whole determination can be carried out in a few hours with a simple apparatus and the results obtained on a number of different types of oil appear to be capable of correlation with the behaviour of these oils in practice. Not only can the oxidizability of new oils be determined but the state of oxidation of an old oil can readily be ascertained by the new method. The experimental conditions can be modified to increase or decrease the severity of oxidation so as to discriminate more readily between oils of similar oxidizability at either end of the scale.

A New Laboratory Method for Rating Aviation Fuels. (R. Stansfield and H. B. Taylor, J. Inst. Petrol, Vol. 25, No. 190, August, 1939, pp. 566-572.) (71/37 Great Britain.)

As is well known, the bouncing pin on the C.F.R. engine will not record true knock if the rate of pressure rise of the preliminary (normal) combustion is greater

than that of the subsequent knock. The author proposes as a true measure of the knock the amplitude of the first detonation wave on the dp/dt record as obtained with a cathode ray oscillograph.

Experience has shown that the absolute magnitude of this first detonation wave is very sensitive to engine conditions and varies even if such major factors as compression ratio, mixture strength and temperature and r.p.m. are kept constant. For this reason the pressure amplitude is compared with that obtained with a standard reference fuel under identical running conditions, the term "Knock Ratio" being introduced by the author for the value $\frac{\text{amplitude with test fuel.}}{\text{amplitude with ref. fuel.}}$

The octane number corresponding to this knock ratio can be obtained subsequently by matching. The comparison is carried out first for mixture strength giving maximum knock (as measured by height of detonator wave) and then for richer mixtures. The results show that whilst most fuels appreciate in terms of the reference fuels (C. and F. mixture) some depreciate, and difference between various fuels tend to become more pronounced. For this reason the authors recommend that the specification for knock testing of an aviation fuel should cover two ratings corresponding to weak and strong mixtures respectively. Satisfactory agreement with full scale rating is claimed for the new method.

Experimental Study of Deformation and of Effective Width in Axially Loaded Sheet-Stringer Panels. (W. Ramberg, A. E. McPherson and S. Levy, N.A.C.A. Tech. Note No. 684, Feb., 1939.) (71/38 U.S.A.)

The deformation of two sheet-stringer panels subjected to end compression under carefully controlled end conditions was measured at a number of points and at a number of loads, most of which were above the load at which the sheet had begun to buckle. A technique was developed for attaching Tuckerman optical strain gauges to the sheet without disturbing the strain distribution in the sheet by the method of attachment. The twisting and the bending of the stringers were measured by means of pointers attached to the stringers.

A detailed comparison was made between the measured deformation of the buckled sheet and the deformation calculated from approximate theories for the deformation in a rectangular sheet with freely supported edges buckling under end compression advanced by Timoshenko, Frankland, and Marguerre.

It appears that the various theories advanced so far do not fit the observations consistently. Thus Marguerre predicts both sheet load and effective width very accurately, but is hopelessly out in his estimate of transverse strain distribution.

The analysis of measured stringer deformation was carried out by Southwell's method (deformation plotted against deformation overload). It was concluded that the stringer failure in the tests was due to instability under continued twisting and bending.

Effect of Service Stresses on Impact Resistance, X-Ray Diffraction Patterns, and Microstructure of 25 S Aluminium Alloy. (J. A. Kies and G. W. Quick, N.A.C.A. Report No. 659, 1939.) (71/39 U.S.A.)

A great number of tests were made to determine the effect of service stresses on the impact resistance, the X-ray diffraction patterns, and the microstructure of 25 S aluminium alloy. Many of the specimens were taken from actual propeller blades and others were cut from $\frac{13}{16}$ inch rod furnished by the Aluminium Company of America.

The average impact resistances were found to be unchanged even after 288,000 cycles in a 0— to 33,400-pound-per-square-inch range that exceeded the fatigue limit and the original proof stress of the material. The X-ray diffraction patterns were unchanged as regards any indication of structural change resulting from the fatigue stressing of the alloy. Two structural conditions known as slip-plane

precipitation and veining were observed. The service stresses were not responsible for the slip-plane precipitation and the endurance limit was reduced by it. Veining could be made to disappear and reappear by alternate solution heat treatment and age hardening.

Stability of Rectangular Plates with Longitudinal or Transverse Stiffeners Under Uniform Compression. (R. Barbre, Ing. Archiv., Vol. 8, No. 2, 1937. N.A.C.A. Tech. Memo., No. 904, Aug., 1939.) (71/40 Germany.)

The proper application of stiffeners, i.e., stiffening ribs fixed to a plate, leads to an increase of the buckling strength of rectangular plates. In calculating stiffened plates, we have to distinguish between:—

1. Plates with large spacing of the stiffeners in which the bending stiffness of the plate and ribs appear separately in the calculation, and
2. Plates with small stiffener spacings for which the bending stiffness of plate and stiffeners in the direction of the stiffeners can be combined to a new bending stiffness, provided the stiffeners all have the same cross section. In general, we are allowed to treat such plates as orthotropic plates.

In the present paper, the complete buckling conditions of stiffened plates are developed for uniform compression plates with one or two longitudinal or transverse stiffeners at any point being considered. (Stiffeners in the direction of normal loading are called longitudinal, transverse stiffeners being perpendicular to the loading.)

For the special case with any number of longitudinal stiffeners with equal dimensions and with equal spacings, Lokshin has calculated the buckling conditions. As shown by the author of the present paper, these conditions are not complete.

Metallic Coatings and Their Corrosion Resistance (Part I). (S. G. Clarke, Metal Industry, 28/7/39, pp. 87-90. Metropolitan-Vickers Technical News Bulletin, No. 672, 18/8/39, p. 5.) (71/41 Great Britain.)

The author deals with the resistance of nickel and chromium coatings to outdoor exposure. Since the value of a coating depends primarily on its remaining intact, the author made investigations into the length of time required for a certain amount of corrosion to occur. He deals with nickel which is widely used as an undercoat to chromium but rarely by itself as a protective coating for steel for outdoor purposes due to its porosity and high rate of corrosion. Chromium, probably the most resistant of the non-precious metals to atmospheric corrosion, is also discussed.

Illustrated with four tables.

Kenametal. (Iron Age, 7/9/39, p. 45. Metropolitan-Vickers Tech. News Bull., No. 677, 22/9/39, p. 7.) (71/42 Great Britain.)

The article describes a new carbide tool metal which, it is claimed, is capable of machining steels of all hardnesses with practical economy. The material is known as Kenametal and is produced with the metallic compound $W.Ti.C_2$ as the essential ingredient. Tool tips of this new material have been used for cutting steels of 200 to 500 Brinell. A description of the grinding technique required for these new tool tips is explained. Illustrated with two photographs.

The Anodic Oxidation of Aluminium. (J. W. Cuthbertson, J. Inst. Met., July, 1939, pp. 303-325. Met.-Vickers Tech. News Bull., No. 675, 8/9/39, p. 7.) (71/43 Great Britain.)

The anodic oxidation of aluminium in a number of different electrolytes, using a.c. electrolysis has been investigated with the aid of the cathode-ray oscillograph. The effect of the oxide barrier on the form of the current-time and current-voltage

curves has been studied and is shown to depend on the construction of the electrolyte and operating conditions. Owing to a capacity effect, the current and voltage are always out of phase during the whole or a part of each half-cycle. The current-voltage curve consequently is a closed loop, the area of which is proportional to the dielectric loss in the film. The results obtained suggest that, while the mechanism of anodic oxidation in chromic, sulphuric, and oxalic baths is similar, chromic acid solutions should produce the more satisfactory films.

Illustrated with two diagrams, eight graphs and two tables.

The Creep Properties of Soft Solders and Soft Soldered Joints. (W. A. Baker, J. Inst. Met., July, 1939, pp. 327-347. Met.-Vickers Tech. News Bull., No. 675, 8/9/39, p. 7.) (71/44 Great Britain.)

Chill-cast soft solders were subjected to long-time creep tests at room temperature and at 80°C. In the range of tin-lead-alloys tested, the eutectic was most resistant to creep. The alloys of lower tin content, tinman's and plumber's solders had much lower resistance to creep at both temperatures. Antimonial solders with antimony contents equal to 6 per cent. of their tin contents were 2 to 4 times as resistant to creep as the corresponding non-antimonial alloys. Single-lap soft-soldered joints on mild steel, copper, and brass were subjected to prolonged shear stress at room temperature and at 80°C. The creep strength of the joint was determined by the creep properties of the solder film, the latter being dependent on the solder used, and on the alloying, if any, with the material joined.

Illustrated with one photograph, two diagrams, five graphs and five tables.

Some Corrosion Problems Relating to Modern Aircraft. (A. J. Sidery and W. W. Willstrop, J. Roy. Aeron. Soc., August, 1939, pp. 606-628.) (71/45 Great Britain.)

The authors deal with a number of isolated problems arising during the operation of modern aircraft without discussing general principles or the theoretical aspect of the subject.

Considerable space is given to the effect of heat treatment on the corrosion resistance of Aluminium Alloys and the temporary protection afforded by pigmented wax-hardened lanolin preparation is discussed.

Although not intended to take the place of paint, the lanolin preparation has the advantage of ease of application and low surface weight (.6 oz. per sq. yard against 2 oz. for enamel coating).

Radiator corrosion due to glycol can be considerably reduced by an inhibitor (triethanolamine plus phosphoric acid).

The authors conclude that complete prevention of corrosion in all metals and alloys is something which is extremely unlikely ever to be achieved.

In nature, the metals are combined with other elements and subsequent purification does not alter the natural affinity for returning to the combined state.

Metallic Coatings and Their Corrosion Resistance (Part II). (S. G. Clarke, Met. Ind., 25/8/39, pp. 181-184. Met.-Vickers Tech. News Bull., No. 674, 1/9/39 (p. 8). (71/46 Great Britain.)

The tests carried out in connection with the corrosion-resisting properties of certain metallic coatings are described. All the tests were carried out indoors, and the results of these tests after one year are given. In conclusion, the author discusses the results of his experiments, both indoor and outdoor, and suggests various reasons for the corrosion of metallic coatings, and ways of preventing it.

Illustrated with two tables and one graph.

Compressive Tests of a Monocoque Box. (W. Ramberg, A. E. McPherson and S. Levy, N.A.C.A. Tech. Note, No. 721, August, 1939.) (71/47 U.S.A.)

The following conclusions were drawn from the compressive tests of the monocoque box specimen of aluminium alloy for this investigation.

1. The loading fixtures were adequate in producing uniform compressive strain over the section of the specimen.

2. The special equipment for measuring stringer strains on a specimen of this type gave consistent and reproducible results.

3. The 0.026 inch sheet between stringers buckled at a stress of about 2,500 pounds per square inch and the 0.075 inch shear web buckled at a stress of about 8,800 pounds per square inch. These values were in agreement with the theoretical buckling stresses for rigid clamping of the sheet at the edges parallel to the load. Permanent set became noticeable at a load of 115,200 pounds; this value corresponded to an average stress in the stringers of about 16,000 pounds per square inch.

4. The measured strain at the stringer centroids near the midsection of the box are within 10 per cent. of the measured average strains up to the maximum load of 115,200 pounds. The measured average strain at the midsection was within 2 per cent. of calculated strain at all loads up to the maximum load of 115,200 pounds. The calculated strain was obtained by dividing the load by the product of Young's modulus and effective cross-sectional area, the effective area of the sheet being obtained from Maguerre's formula for a sheet with simply supported edges and from Cox's formula for a sheet with known buckling strain. These formulas had given effective widths in agreement with measured values for the panels described in Technical Note No. 684. (See Abst. No. 71/38.)

Local Instability of Centrally Loaded Columns of Channel Section or Z-Section. (E. E. Lundquist, N.A.C.A. Tech. Note, No. 722, Aug., 1939.) (71/48 U.S.A.)

CONCLUSIONS.

1. The critical compressive stress at which cross-sectional distortion occurs in a thin-wall column of channel section or Z-section is given by either of the following equations:—

$$f_{cr} = \frac{\{ n\, k_F\, \pi^2\, E\, t_F^2 \}}{\{ 12\, (1-\mu^2)\, b_F^2 \}} \qquad f_{cr} = \frac{\{ n\, k_W\, \pi^2\, E\, t_W^2 \}}{\{ 12\, (1-\mu^2)\, b_W^2 \}}$$

where

E and μ are Young's modulus and Poisson's ratio for the material, respectively.

b_F and b_W, the width of the flange and the web, respectively.

t_F and t_W, the thickness of the flange and the web, respectively.

k_F and k_W, non-dimensional coefficients.

n, a factor taken so that nE gives the effective modulus of the flange and web at stresses beyond the elastic range.

2. At stresses beyond the elastic range, the value of the effective modulus nE, for local buckling of thin-wall columns of channel-section and Z-section will depend upon tests. In the absence of such tests, however, it is reasonable to assume that n is a function of τ, where τE is the effective modulus of an ordinary column at stresses beyond the elastic range. A careful study of the theory and such experimental data as are available indicates that it is conservative to assume

$$n = \frac{(\tau + 3\sqrt{\tau})}{4}$$

provided that τ is evaluated by use of the accepted column curve for the material.

The Fundamentals of Stress Optical Investigations. (N. G. Tchentzow and G. A. Ozerow, Trans. C.A.H.I., No. 270, 1936.) (71/49 U.S.S.R.)

The present paper contains the theoretical basis and some practical recommendations concerning the photoelasticity method.

Chapter I deals with elastic theory. The equations show the relationship between the stresses in models made from different materials but subjected to the same conditions of loading.

Chapter II discusses the electromagnetic theory of light and the relations between the parameters of the Fresnel ellipsoid and the strain parameters.

Chapter III deals with interference phenomena.

Chapter IV describes methods of plotting isoclinic and isostatic lines and discusses their properties with special reference to the neighbourhood of singular points.

Chapter V discusses several methods for measuring differences in principal stress and the graphical method for eliminating initial stress is described.

Chapter VI deals with different methods of separating principal stress.

Appendix I gives a detailed comparison between the experimental investigation of the case of a disc compressed along a diameter and the theoretical solution.

Appendix II gives an extended bibliography.

(The Soviet Government attach special importance to this report and have arranged for a larger edition than is normally the case for the transactions of the C.A.H.I.)

Analysis of Spherical Shells of Variable Wall Thickness. (M. F. Spotts, J. App. Mech., Vol. 6, No. 3, Sept., 1939, pp. 97-102.) (71/50 U.S.A.)

This article presents a solution to the problem of finding the forces and moments which occur in a spherical shell which is axisymmetrically loaded, when the variation in wall thickness is taken as a quadratic function of the co-ordinate of latitude.

The so-called Love-Meissner differential equations for the case of non-uniform wall thickness are derived. By appropriate substitutions these are reduced to one linear equation of the fourth order having constant coefficients. The solution to this equation when taken in the homogeneous form is first given. This homogeneous solution will be the general solution for all problems where the shell surface is free from external force, and the only loads on the shell consist of forces and moments applied at the boundaries.

When, however, the shell surface itself is loaded, a particular integral (which will depend upon the type of loading) must also be obtained for the non-homogeneous equations.

The method of solution contained herein is illustrated by a numerical example for a shell of one boundary when acted upon by dead-load forces, and the results are plotted.

A Theory of Flexure for Beams with Non-Parallel Extreme Fibres. (W. R. Osgood, J. App. Mech., Vol. 6, No. 3, September, 1939, pp. 122-6.) (71/52 U.S.A.)

A theory of flexure for beams with non-parallel extreme fibres is presented. The theory is shown to reduce to the ordinary theory of flexure as the angle between the extreme fibres approaches zero. Maximum fibre stresses computed by the theory and by the ordinary theory for a plate girder with non-parallel flanges show that for angles between the flanges up to twenty degrees the ordinary theory can never be in error more than about five per cent., but for larger angles the error in general increases rapidly with the angle. Finally an example is given of the application of the theory as an approximation to a beam with curved extreme fibres. In this case the theory was confirmed by the results of tests.

Clamped Rectangular Plates with Centre Concentrated Load. (D. Young, J. App. Mech., Vol. 6, No. 3, September, 1939, pp. 114-116.) (71/51 U.S.A.)

A general method of solution for rectangular plates with clamped edges and any kind of loading has been developed by Professor S. P. Timoshenko (1). The present paper gives the results of calculations using this method for the maximum deflection, moment, and edge shears for rectangular plates of various proportions with all four edges clamped and loaded by a single concentrated load at the centre. Similar data for a clamped rectangular plate with a uniformly distributed load have been given by I. A. Wojtaszak and also T. H. Evans (2). A report of an experimental investigation of this problem with some analytical results has been given by R. G. Sturm and R. L. Moore (3).

Static and Dynamic Model Similarity. (F. Nagel, J. Aeron. Sci., Vol. 6, No. 11, Sept., 1939, pp. 468-469.) (71/53 U.S.A.)

In many cases applied air loads cause deflections in the structure of an aeroplane which in turn change these loads to a very large extent, especially if an unstable equilibrium condition is approached. In actual aeroplane design, this is primarily known as wing divergence and flutter. The analytical treatment of these cases is in general very involved and can often be carried out only with simplifying assumptions. An entirely different method of approach is to build an elastically similar model and test it in the wind tunnel. A brief summary of the similarity laws which govern these conditions is given by the author.

Analysis of Circular Rings for Monocoque Fuselages. Additional Help in Beam-Leg Identification. (J. A. Wise, J. Aeron. Sci., Vol. 6, No. 11, Sept., 1939, pp. 460-463.) (71/54 U.S.A.)

The distribution of reactions to loads transmitted by rings to skin in a monocoque fuselage is discussed. Formulas are derived for the moment, shear, and axial stress at all points in circular rings which are subjected to a moment, a radial force, or a tangential force applied at one point on the circumference. Curves are given for each case and their use in obtaining the stresses in the ring under any loading by superposition of separate effects is illustrated by an example.

Strip Welding. (D. A. McArthur, Steel, 28/8/39, pp. 42-64. Metropolitan-Vickers Tech. News Bull., No. 676, 15/9/39, p. 3.) (71/55 Great Britain.)

The highest possible efficiency of handling operations is an essential requirement of modern strip welding lines. The author gives in his article a description of modern procedure equipment and methods. Comparisons are made between the relative times required for joining the ends of successive coils by stitching the ends, and by flash welding, and some figures relating to these two methods are given. Problems with regard to alignment and location of the strips through the shears and welding machine are discussed and the best feed speed is considered.

Illustrated with one photograph.

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(1) "Bending of Rectangular Plates With Clamped Edges," by S. P. Timoshenko, Proceedings of the Fifth International Congress for Applied Mechanics, Cambridge, Mass., September, 1938. For abstract see *Journal of Applied Mechanics*, Trans. A.S.M.E., Vol. 60, September, 1938, p. A-132.

(2) "The Calculation of Maximum Deflection, Moment, and Shear for Uniformly Loaded Rectangular Plate With Clamped Edges," by I. A. Wojtaszak, *Journal of Applied Mechanics*, Trans. A.S.M.E., Vol. 59, December, 1937, p. A-173. Also "Tables of Moments and Deflections for a Rectangular Plate Fixed on All Edges and Carrying a Uniformly Distributed Load," by T. H. Evans, *Journal of Applied Mechanics*, Trans. A.S.M.E., Vol. 61, March, 1939, p. A-7.

(3) "The Behaviour of Rectangular Plates Under Concentrated Load," by R. G. Sturm and R. L. Moore, *Journal of Applied Mechanics*, Trans. A.S.M.E., Vol. 59, June, 1937, p. A-75.

X-Ray as a Production Tool. (O. T. Barnett, Steel, 28/8/39, pp. 38-41. Metropolitan-Vickers Tech. News Bull., No. 676, 15/9/39, p. 3.) (71/56 Great Britain.)

The article gives a description of a portable 400,000 volt X-ray machine and describes the use of penetrameters. A set of examples of exographs show a typical bad weld, and a description of the technique used to obtain them is given. The use of fluorescent screens intensifies the exograph negative and result in considerable saving in exposure time. The author considers that as knowledge of radiography is gained by those concerned so will X-ray apparatus become more generally used as a production tool.

Illustrated with ten photographs and one diagram.

New Types of Heat-Treating and Process Control Apparatus. (F. J. Oliver, Iron Age, 3/8/39, pp. 50-3. Metropolitan-Vickers Tech. News Bull., No. 673, 25/8/39, p. 1.) (71/57 Great Britain.)

This article gives a description of the various new types of instruments used for measuring temperatures, pressures, and other factors governing heat-treating and process work. Amongst the apparatus described is a gas calorimeter and a pocket CO_2 indicator. Longer life is claimed in a new type of heat-treating box, and also a longer electrode life is claimed for a new type of electric pot furnace.

Illustrated with ten photographs and one diagram.

Machines for Surface Hardening by the Shorter Process. (Industrial Gases, June, 1939, pp. 61-70. Metropolitan-Vickers Tech. News Bull., No. 673, 25/8/39, p. 8.) (71/58 Great Britain.)

The success of the Shorter process depends upon strict control of the extent and duration of heating and quenching, by means of suitable mechanical devices. These are classified, according to the relative movement between burner, quench and job, into four classes. The article describes a typical machine in each class, showing how the fundamentals of each process have been carried out in respect of different classes of work. The machines described include the Shorter water-cooled blowpipe, the heavy-duty blowpipe, the ring burner blowpipe, the Shorter gear hardening machine, the Shorter-Griesogen automatic gear hardening machine and the Gleason gear hardening machine.

Illustrated with nineteen photographs.

Metal Spraying. (C. Cleveland, Metal Industry, August, 1939, pp. 361-4. Metropolitan-Vickers Tech. News Bull., No. 673, 25/8/39, p. 8.) (71/59 U.S.A.)

The author first traces developments which have taken place in metal spraying during the last forty years, and describes some of the methods adopted. The modern method of metal spraying, introduced shortly after the use of oxygen and acetelyne for welding, is then described, and the construction of recent metal spraying machines is discussed in detail. Finally, the advantages and disadvantages of the process are enumerated, together with the uses to which it can be put, and the various kinds of metals that can be used. The article also describes precautions which must be taken before a surface can be sprayed.

Illustrated with seven photographs and two diagrams.

Metal Spraying with Chromium Steel. (P. Leder, Steel, 31/7/39, pp. 38-9. Metropolitan-Vickers Technical News Bulletin, No. 672, 18/8/39, p. 5.) (71/60 Great Britain.)

Results obtained in the spraying of worn machine parts with chromium steels seem to indicate that high carbon, plain chromium rustless steel is superior in its

wear resistance to simple carbon steel of the same sprayed hardness. Examples of such spraying and the savings effected thereby are cited.

Illustrated with two photographs.

Modern Metal Cleaning (Part I). (Mechanical World, 4/8/39, pp. 99-102. Metropolitan-Vickers Technical News Bulletin, No. 672, 18/8/39, p. 6.) (71/61 Great Britain.)

The fundamentals of solvent cleaning of metals and recent industrial applications of plant for this purpose are reviewed. Special reference is made to degreasing and cleaning by means of trichlorethylene plant. The principles on which the plant is designed, and the various precautions which must be observed in its installation so as to avoid undue risk to the operator, are discussed. The capacity, adaptability, operation, means of heating and cooling are also dealt with in some detail.

Illustrated with two photographs and one table.

Superfinish. (A. M. Swigert, Machinist, 5/8/39, pp. 364E-367E. Metropolitan-Vickers Technical News Bulletin, No. 672, 18/8/39, p. 6.) (71/62 Great Britain.)

The author describes the various methods of finishing metal surfaces, such as honing, grinding, etc., and the quality of surface so produced. He then describes apparatus, such as the profilometer, for measuring the quality of surface smoothness, loading properties and general characteristics of surfaces finished by the above methods. The most up-to-date method of finishing, i.e., superfinishing, is briefly described and the results obtained are compared with the results obtained by other methods.

Illustrated with eighteen diagrams.

Automatic Arc Welding. (E. Rosenberg, Welder, Aug., 1939, pp. 239-243. Met.-Vickers Tech. News Bull., No. 675, 8-9-39, p. 8.) (71/63 Great Britain.)

After discussing methods of applying flux to the parts to be welded the author describes methods of automatic feed for the electrode such as by means of a small feeding motor, the armature of which is connected to the armature of a small d.c. control generator with differentially wound field coils. One coil is connected across the arc and the other is excited permanently from a constant voltage exciter. By suitably winding these coils, a change of arc voltage due to a change in length of arc causes the fields of these coils to become unbalanced, hence feeding the electrode as required. The author finally describes large tube welding machine and gives examples of methods used for various work.

Illustrated with four photographs and one diagram.

Automatic Arc Welding Without the Aid of Machines. (G. Hafergut, Z.V.D.I., 19/8/39, pp. 951-2. Met.-Vickers Tech. News Bull., No. 674, 1/9/39, p. 2.) (71/64 Great Britain.)

The author gives details of a simplified method of automatic welding called the "Elin-Hafergut" process for the welding of long straight seams without the aid of machines. All that is required is an auxiliary device in the form of bar made of copper, aluminium or magnesium containing a groove on the underside in which the electrode is held fast without possibility of displacement. Up to now welds have been made in one operation with electrodes 1½ metres long which is not regarded as the limit.

Illustrated with two diagrams and one photograph.

Examination by X-Rays. (R. Mondon, Airc. Prod., Sept., 1939, pp. 386-392. Met.-Vickers Tech. News Bull., No. 674, 1/9/39, p. 8.) (71/65 Great Britain.)

Due to the very high standard of inspection demanded by the A.I.D. for certain components, X-ray examination of metal parts, particularly castings, is now finding an important place in aero-engine and air-frame production. This article gives a description of the application of X-rays to aero-engine production in the works of the Hispano-Suiza Company in France. The author first gives a short account of the theory underlying X-ray principles and then follows a description of the equipment used in these works. The illustrations are actual radiographs from the Hispano-Suiza laboratory. He ends the article by a description of the methods used for X-ray examination of parts such as bearings, valves, castings, and pistons.

Illustrated with seven photographs, seven radiographs, five diagrams, two graphs and one table.

Aircraft Fire Fighting Equipment. (Engineer, Volume 168, No. 4363, 25/8/39, pp. 217-219.) (71/66 Great Britain.)

The article describes the " Graviner " automatic equipment which utilises methyl bromide gassed with nitrogen to a pressure of 60 lb. per sq. in. Six pounds of this chemical is contained in a copper bottle weighing 3 lb. and released by an electrically operated fuse which fires an explosive charge and blows out the stopper, leaving an unrestricted passage for the flow. The chemical is distributed to various danger points, such as engine intake, exhaust stubs, blower system, etc.

The main fuse on the pressure bottle can be operated either by hand (electric switch) or automatically.

The automatic switches are of two kinds:—

1. Inertia and gravity switches which close the circuit either under conditions of sudden impact (deceleration greater than 6 g.) or if the aircraft inadvertently turns on its back during landing.
2. Flame and temperature operated switches which come into action if the temperature at their locality exceeds a critical value (e.g., 150°C).

Twelve diagrams show details of the various components and illustrate the electric wiring.

Aircraft Rate-of-Climb Indicators. (D. P. Johnson, N.A.C.A. Tech. Report, No. 666, 1939.) (71/67 U.S.A.)

The theory of the rate-of-climb indicator is developed in a form adapted for application to the instrument in its present-day form. Compensations for altitude, temperature, and rate of change of temperature are discussed from the designer's standpoint on the basis of this theory. Certain dynamic effects including instrument lag, and the use of the rate-of-climb indicator as a statoscope are also considered. Modern instruments are described. A laboratory test procedure is outlined and test results are given.

The " Riken " Explosive Gas Indicator. (J. S. Jackson, J. Inst. Petroleum Technologists, July, 1939, pp. 456-8. Metropolitan-Vickers Tech. News Bull., No. 673, 25/8/39, p. 2.) (71/68 Great Britain.)

The " Riken " explosive gas indicator, designed by Dr. Z. Tuzi, is based on a principle described in a bulletin of the U.S. Bureau of Mines as long ago as 1913. The indicator relies on the fact that the refractive index of methane is considerably higher than that of air, and incorporates the Doi refractometer, which is similar in principle to the Jamin interferometer. The author describes the indicator in detail and enumerates its advantages. It has great sensitivity, and can be used

to detect extremely small quantities of gasolene in the air. To conclude, an account of the method of carrying out a test, and a set of typical results are given.

Illustrated with one photograph and one diagram.

Notes on the Dynamics of Electrical Measuring Instruments. (T. A. Rich, G.E. Review, July, 1939, pp. 311-6. Metropolitan-Vickers Tech. News Bull., No. 673, 25/8/39, p. 3.) (71/69 Great Britain.)

This article attempts to interpret the fundamental equations in order to facilitate the use of instruments in practical applications to unusual conditions. The equations used cover a wide range of instruments, amongst them being :—d'Arsonval type instruments used either below or above their natural frequency and alternating current instruments. Solutions to these equations are also given as well as the most convenient way of solving them. The article concludes with a discussion on the evaluation of the dynamic characteristics of instruments.

Illustrated with one photograph and six graphs.

Development in the Measurement of Air Flow in Mines. (R. Poole, A. W. Leadbeater, Engineering, 11/8/39, pp. 182-5. Metropolitan-Vickers Tech. News Bull., No. 673, 25/8/39, p 5.) (71/70 Great Britain.)

The design and application in mines of a spring-controlled vane-type air flow meter known as the Velometer and developed by Dr. Boyle in the United States is described. Certain improvements have been made by the Metropolitan-Vickers Electrical Co. (reduction in damping and pivot friction).

By paying special attention to the pivots and using more sensitive springs it has been found possible to measure velocities as low as 1/10 ft. per second. This represents a velocity pressure of only $2\frac{1}{4}$ millionths of an inch of water.

Illustrated with four photographs, two tables, six diagrams.

Instantaneous Fluid Pressure Recording Equipment. (S. E. Goodall and R. B. Smith, Engineering, 4/8/39, pp. 127-9. Metropolitan-Vickers Technical News Bulletin, No. 672, 18/8/39, p. 1.) (71/71 Great Britain.)

The authors describe equipment developed for instantaneous fluid-pressure recording with special reference to the measurement of pressure rise within switchgear tanks. The principle employed is that the pressure measured produces small capacity changes in a pressure unit which are translated into large current changes in an oscillograph element. Diagrams of the circuit employed are given and details of results obtained and other applications of the equipment are outlined.

Illustrated with nine diagrams.

Liquid Level Control and Distant Indicators. (F. R. Smedley, El. Engineer, 25/8/39, pp. 658-662. Metropolitan-Vickers Technical News Bulletin, No. 674, p. 7.) (71/72 Great Britain.)

The author shows the construction and operation of the " Noflote " control system developed by Evershed and Vignoles, Ltd., the Bore-Hole Depth Indicator, the Plumb-Bob Depth Indicator, the Plumb-Bob Tide level Indicator and Recorder, the Midworth Water level transmitter, and the C. and S. No-contact system. He also describes the " Tangent " audible water level indicator, the " Borough " electric float operated transmitter, made by Gent and Co., Ltd., and the Automatic Water system pumping outfit made by H. J. Godwin, Ltd.

Illustrated with eight photographs and eight diagrams.

" *Autosyn* " *Application for Remote Indication of Aircraft Instruments.* (W. A. Reichel and R. C. Sylvander, J. Aeron. Sci., Vol. 6, No. 11, Sept., 1939, pp. 464-467.) (71/73 U.S.A.)

The " Autosyn " system has been developed by the Pioneer Instrument Co.,

U.S.A., to provide a reliable and accurate method of remote indication of such functions as fuel pressure, engine speed, fuel flow and wheel and control surface position. For large machines, the usual method, such as pipe lines or flexible shafts, becomes unsafe and impracticable due to the increased distance between engine or control surface from the cockpit. The Autosyn system is entirely electrical and consists of a transmitter and receiver, each having 3 phase 2 pole stators and single phase 2 pole rotors. Alternating current is supplied to the rotors of transmitter and receiver and the stator leads of one Autosyn are connected to the corresponding stator leads on the other. The rotor currents induce a definite set of voltages across the stator leads, any one position of the rotor corresponding to 3 voltages. If both rotors happen to be in the same relative position, the induced voltages are equal and opposite and non-current flows through the stator, i.e., no torque is produced. If the rotors are initially in different positions, a current will flow causing them to get into step. The system thus operates as a flexible coupling, and the error can be kept easily within 1°. More than one indicator can be run off the same " master " with a slight drop in resultant accuracy. The latest type of Autosyn for aircraft weighs less than 4 oz. per instrument.

The Calibration of Four-Aerial Adcock Direction Finders. (W. Ross, J. Inst. Elec. Eng., Vol. 85, No. 512, Aug., 1939, pp. 192-202.) (71/74 Great Britain.)

The paper describes how it is possible to determine the minimum radius at which a four-aerial Adcock direction-finder may be calibrated for instrumental error without introducing spurious effects due to the proximity of the calibrating transmitter to the direction-finder. It is shown that this minimum radius depends upon the spacing of the aerials, the wavelength, and the inherent accuracy of the direction-finder to be calibrated. In most cases of practical interest the minimum radius is found to be between 0.6λ and 3.5λ. Such distances, while usually easily attainable on the short wave band, may not be possible in the case of medium or long wavelengths.

Radio in Aviation—General Survey with Special Reference to the R.A.F. (with Discussion.) (J. Inst. Elec. Eng., Vol. 85, No. 512, Aug., 1939, pp. 215-241.) (71/75 Great Britain.)

The paper discusses the conditions peculiar to aircraft operation in respect of radio-telegraphy and radio-telephony. Particular stress is given to those conditions not usually met with in other applications of radio-communication and especially to the sources of interference to reception and of danger to the aircraft and its occupants.

It concludes with a brief reference to a few special applications of radio in aviation, and while no attempt is made to describe the equipment itself the fundamental principles on which its construction is based are briefly given.

Measurement of Potential by Means of the Electrolytic Tank. (G. Hepp, Philips' Technical Review, Aug., 1939, pp. 223-230. Met.-Vickers Tech. News Bull., No. 675, 8/9/39, p. 3.) (71/76 Great Britain.)

If an electrode system with fixed electrode potentials is immersed in a conducting liquid the variation of potential between the electrodes will remain practically unchanged. The variation of potential in the liquid can now be measured by means of a probe electrode. An apparatus is described whereby potential fields can be measured and recorded on this principle with the help of models. Several applications are discussed and it is explained in particular how it is possible to reconstruct the paths of the electrons in vacuum tubes by using this apparatus.

Illustrated with four photographs and five diagrams.

The Image Iconoscope. (H. Iams, G. A. Morton and V. K. Zworykin, Proc. Inst. Rad. Eng., Vol. 27, No. 9, Sept., 1939, pp. 541-547.) (71/77 U.S.A.)

An iconoscope having increased sensitivity is to be desired for purposes of improving studio conditions, making possible more universal outdoor work, and permitting greater depths of focus. The new tube described obtains its high sensitivity by making use of an electron instead of an optical image of the scene to be transmitted, projected onto a scanned mosaic. The method permits more efficient and better photo-cathodes, and also secondary-emission image intensification at the mosaic, resulting in a sensitivity 6 to 10 times greater than that of the standard iconoscope operated under the same conditions. The translucent photo-cathode is made by evaporating silver on a transparent surface, oxidising, treating with caesium, and evaporating more silver. The electron image may be focused by either electrostatic or magnetic fields. Several types of mosaics are suitable for receiving and storing the electron picture.

Approximation to a Function of One Variable from a Set of its Mean Value. (M. Greenspan, Nat. Bur. of Stand., Journal of Research, Vol. 23, No. 2, August, 1939, pp. 309-317.) (71/78 U.S.A.)

Measurements involving the variation of a function with its argument generally only cover mean values over an interval. Thus a strain gauge measure total extension over a certain length and the mean strain thus obtained may differ considerably from the actual strains at the centre of the gauge length. The author describes two types of formulæ known respectively as the " central difference " and " descending difference " formula which enable absolute value as distinct from mean values to be computed and which are strictly accurate provided the function under investigation is a polynomial or finite degree n. Although this strict accuracy is not always possible, the use of the formulæ is still justified on the ground that distribution encountered in practice are frequently of a type approximating to a polynomial of low degree. The highest order of difference which can be given advantageously used is determined by the accuracy of the experimental data. Successive differences are increasingly affected by errors of measurement and may ultimately consist almost entirely of accumulated error. For this reason it may be desirable to graduate the function before the difference formulæ are applied.

The author concludes with two worked out examples of the method.

The Spring Clutch. (C. F. Wiebusch, J. App. Mech., Vol. 6, No. 3, Sept., 1939, pp. 103-8.) (71/79 U.S.A.)

A mathematical theory is developed for the spring clutch which consists of two coaxial cylinders placed end to end and coupled torsionally by a coil spring fitted over them. Relations are derived whereby it is possible to design spring clutches in terms of the requirements and the constants of the spring material. Experimental verification of the relations is given. The theory of residual and active stresses as applied to the springs is discussed.

The relations developed are sufficient to determine uniquely the correct spring dimensions for a spring clutch of specified free and gripping torque provided the material constants and the cross-sectional shape (round or rectangular) of the wire as well as the length and diameter of the clutch arbour, are specified. Choice of values for the last two factors is based largely on permissible heating resulting from the slipping in the free direction. If only maximum values of the free torque and minimum values of the gripping torque are given, a number of solutions can be obtained from which to choose the most convenient. By combining the relations derived, in a manner to permit step-by-step calculation, the design of spring clutches is reduced to a simple routine.

World Oil Production, with Special Reference to the U.S.S.R. (Inter. Avia., No. 675, 27/9/39, pp. 1-3.) (71/80 Switzerland.)

The following table shows the 1938 output of the principal oil producing countries:—

U.S.A.	...	...	170 million tons
U.S.S.R.	...	...	30 ,, ,,
Venezuela	...	...	28 ,, ,,
Iran	...	...	10 ,, ,,
Dutch East Indies		...	7·5 ,, ,,
Rumania	...	...	6.5 ,, ,,
Mexico	...	...	4.8 ,, ,,

Poland comes eighteenth on the list with an annual total of 500,000 tons.

All geologists agree that the Soviet deposits are the mightiest in the world and may account for about a half of the world's entire deposits. Although the U.S.S.R. is thus an important oil power, it does not rank very high as regards oil exports (1.1 million tons in 1938). In the same period Germany consumed 7.3 million tons of which 2.7 million tons were covered by domestic production. The German war-time consumption may be as high as 12 and 15 million tons a year (French estimates). It is clear that Russian and Rumanian imports will have to play an important part in meeting this demand. (Baltic and Danubian waterways as well as rail traffic across new Polish border will be available.)

Measurement and Analysis of Noise and Vibration. (D. Silverman, Instruments, Aug., 1939, pp. 205-236. Met.-Vickers Tech. News Bull., No. 675, 8/9/39, p. 3.) (71/81 Great Britain.)

The author deals with recent developments in acoustical design and describes the two general types of instruments for the study of noise and enumerates the factors influencing the readings. Total sound meters (subjective and objective types) are also considered. The principle of general sound wave analysis is explained and the resonating and heterodyne types of analysing instruments are described, followed by a discussion of special types of analysing instruments.

Illustrated with twelve diagrams, eight graphs and fourteen photographs.

On the Simple Chromatic Photographic. (D. Nukiyama, Aer. Res. Inst., Tokio Report, No. 178, July, 1939.) (71/82 Japan.)

A special photographic camera which gives a simple-chromatic photograph is discussed. With this instrument the problems of contrast, specially the contrast of the image of an object in a foggy atmosphere, are studied. It is proved that with this instrument, the distance of vision can be increased about 10 per cent. to 20 per cent. compared with that of normal vision in a foggy atmosphere.

LIST OF SELECTED TRANSLATIONS.

NOTE.—Applications for the loan of copies of translations mentioned below should be addressed to the Under-Secretary of State, Air Ministry (R.T.P.), Dept. ZA, London, W.C.2, and will be loaded, as far as availability of stocks permit. Suggestions concerning new translations will be considered in relation to general interest and facilities available.

Lists of selected translations have appeared in this publication since September, 1938.

TRANSLATION NUMBER AND AUTHOR.	TITLE AND JOURNAL.
AIRCRAFT AND ACCESSORIES.	
950 Thurow, G.	*The Heinkel Catapult K.10.* (Jahrbuch der deutschen Luftfahrtforschung, Vol. 3, 1938, pp. 143-4.)
951 Hesselbach, B. ...	*Unstable Conditions of Flight.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 1, pp. 229-32.)
961 Petzold, L.	*Shell Structures Made by the Dornier-Werke.* (Jahrbuch der deutschen Luftfahrtforschung, Vol. 1, 1938, pp. 474-81.)
966 Sottorf, W.	*Take-off and Landing in Model Experiments.* (W.R.H., Vol. 20, No. 9, May, 1939, pp. 113-8.)
AERODYNAMIC THEORY.	
939 Vandrey, F.	*Theoretical Investigation of Wing/Body Interference.* (L.F.F., Vol. 14, No. 7, 1937, pp. 347-55. Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 1, pp. 158-66.)
947 Multhopp, H. ...	*The Calculation of the Downwash Behind Wings.* (L.F.F., Vol. 15, No. 9, 1938, pp. 463-7. Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 1, pp. 167-71.)
949 Kochanowsky, W. ...	*Further Results of Calculations of Pressure Distribution Over the Periphery of a Wing Section of Arbitrary Shape.* (Jahrbuch der deutschen Luftfahrtforschung, 1938, Vol. 1, pp. 82-9.)
ENGINES AND ACCESSORIES.	
940 Zeyns, J. ... ... Caroselli, H.	*Determination of the High Altitude Performance of Aero Engines on the Basis of Performance Measurements Made Under Ground Conditions.* (Yearbook of German Aeronautical Research, 1938, Vol. 2, pp. 7-15.)
945 Schmidt, F. A. F. ...	*Method of Improving the Fuel Consumption of Otto Cycle Engines.* (Yearbook of German Aeronautical Research, 1938, Vol. 2, pp. 33-36.)

TRANSLATION NUMBER AND AUTHOR.			TITLE AND JOURNAL.
957	Penzig, F.	... ...	*Visual Examination of Temperature Fields by Means of Temperature Sensitive Paints.* (Z.V.D.I., Vol. 83, No. 3, 21/1/39, pp. 69-74. With Notes by W. Hohenner, Luftwissen, Vol. 6, June, 1939, pp. 195-6.)
			WIRELESS AND ELECTRICITY.
942	Tiberio, U.	... ...	*Measurement of Distance by Means of Ultra-Short Waves (Radiotelemetry).* (Alta Frequenza, Vol. 8, No. 5, May, 1939, pp. 305-23.)
956	Berndorfer, F.	...	*Homing Device Klein ZE Type C.* 63/34. (Jahrbuch der deutschen Luftfahrtforschung, Vol. 3, 1938, pp. 66-9.)

REVIEWS.

Aeroplane Maintenance and Operation.

Various Authors. 1/-, Weekly Parts. George Newnes, Ltd. 1939.

Aeroplane Maintenance and Operation is a new part publication covering the service, maintenance and repair of leading British and American aircraft and aero engine components. If it maintains the standard of its first part the publication will be of considerable use particularly to aircraft mechanics and ground engineers. In its complete volume form the publication will consist of four volumes dealing with engine components, air frame components, instruments and accessory equipment.

In Part I the following are dealt with: the principles of carburation, maintenance and repair of Hobson AVT 95-MB carburettor; the Sperry gyropilot for aeroplanes; the Lockheed airdraulic oleo leg; and the De Havilland controllable pitch airscrew, with notes on the Hamilton hydromatic airscrew. In future parts other types of carburettors will be dealt with; engine starting equipment; aero engine magnetos; aircraft electrical equipment; various types of undercarriages and tail units; aircraft controls; instruments; aeroplane wireless equipment; de-icing equipment and the Link instrument and radio trainer.

The descriptions are clear and a special tribute must be paid to the excellent photographic illustrations and explanatory diagrams.

How We Fly.

Edited by Norman MacMillan. Guild of Air Pilots and Navigators, London. 3/6 net. (Messrs. Virtue and Co., Ltd.)

The Guild of Air Pilots and Navigators of the British Empire has for many years been performing a useful and increasingly important function in guarding the interests of qualified Air Pilots and Navigators. Its first chairman was Air Vice-Marshal Sir Sefton Brancker, in whose memory the Benevolent Fund was founded to help particularly the families of pilots who lose their lives in the service of aviation.

All profits from this book go to help the Guild's Benevolent Fund and on these grounds alone its purchase would be a good thing.

"This interesting book," writes Sir Kingsley Wood, in a foreword "which has been compiled by a number of independent authorities in different spheres of aviation, is published in aid of the Guild of Air Pilots Benevolent Fund. It will be widely read on its own merits, but it deserves a still larger circulation in view of its connection with the effort which is being made to place this most necessary fund on a sound and lasting financial basis, I am very glad to have the opportunity of wishing it all success."

Chapter I deals with the Department of Civil Aviation and is written by Lt.-Col. Sir Francis Shelmerdine, C.I.E., O.B.E., Director-General of Civil Aviation. It is a most excellent survey of the beginnings of civil aviation in the British Empire and its growth and organisation. It is followed by a chapter on Milestones in Air Liner Development by Captain Norman MacMillan, the general editor of the book. The chapter is illustrated with a number of photographs, from the Vickers Vimy commercial air liner of 1919 to the De Havilland Flamingo of 1939 which tells in pictures the whole story of air liner development as neatly and concisely as Captain MacMillan tells it in the letterpress.

Major Hemming writes in Chapter III on the Development of British Air Survey, with all the authority of the expert. It is a most interesting story of endeavour and success. The qualifications necessary for that valuable member of the air community, the ground engineer, are adequately dealt with by Mr. C. T. S. Capel, O.B.E., in Chapter IV, a chapter which is followed by one on the Flying Class and Civil Air Progress by Commander H. E. Perrin, C.B.E., secretary of the Royal Aero Club, and a tower of strength to the flying club movement. Dr. A. E. Slater, Editor of the *Sailplane and Glider*, covers the ground, if one may use the odd analogy, of Aviation Meteorology concisely but adequately for the beginner. The chapter on Sailflying is by Miss Ann C. Edmonds, Instructor of the Surrey Gliding Club, and herself one of the leading gliding pilots.

The whole book is by a galaxy of experts. The right chapter has been written by the right person and surely such an array of air experts has never been gathered together so cheaply before, even for sweet charity's sake. Lieut.-Col. H. W. S. Outram, C.B.E., on Aircraft Production Precepts, I. Harvey on Radio and the Radio Operator, Captain A. G. Lamplugh, F.R.Ae.S., on The History of Aviation Insurance, Flight-Lieut. C. A. Pike, A.F.C., on the Reserves of the Royal Air Force, Captain A. S. Wilcockson, O.B.E., A.F.R.Ae.S., on Atlantic Air Transport, Wing Commander Vernon Brown, O.B.E., on the Investigation of Accidents, George F. Yuill, control officer of Croydon Airport on The Instructor, F. D. Bradbrooke on British Air Transport, D. L. Hollis Williams, B.Sc., F.R.Ae.S., and Captain R. Brie on Safety in Flight, all are men who have deep knowledge of the particular sphere about which they write, and all have added to the value of *How We Fly*.

The last chapter is by Captain R. H. Stocken, Deputy Master of the Guild, who explains what the Guild stands for. His summary of its work, the recognition it has been given, and of its aims, brings home fully what an important part the Guild has already played and how much more important that part must be in the future.

This is a book which no one who buys can fail to find not only of interest, but informative to a degree which can only be obtained by the successful squeezing, as this is, of a quart into a pint pot.

RIPPER'S HEAT ENGINES.

New edition revised by A. T. J. Kersey, A.R.C.Sc., M.I.Mech.E., M.I.A.E., F.Inst. Fuel. Longmans, Green and Co. 1939.

The new edition of this well-known and excellent textbook has been thoroughly revised in the light of the extensive changes in practices during the past few years. This textbook is one which forms an excellent beginning to the study of heat engines. It is written in simple and clear language and the text is amplified with numerous worked out examples. The student who is studying to enter the engine side of aeronautical engineering will find in this book just that kind of instruction to his subject which will give him a sure foundation on which to build the more difficult structure of knowledge later which he will require. At the end of the book are numerous examples for the student to work out.

The publishers are to be congratulated on the excellent make up of this textbook and particularly for the clear illustrations.

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With